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THE UNIVERSITY OF ALBERTA

INTERACTIVE EFFECTS OF NITROGEN AND MOISTURE ON NO-TILL WHEAT PRODUCTION

JACK MERVON CAREFOOT

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE
OF DOCTOR OF PHILOSOPHY

DEPARTMENT OF SOIL SCIENCE

EDMONTON, ALBERTA

(Fall, 1987)

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THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled Interactive Effects of Nitrogen and Moisture on No-till Wheat Production submitted by Jack Mervon Carefoot in partial fulfilment of the requirements for the degree of Doctor of Philosophy in Soil Science.

M Nyborg

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Date October 2, 1987

ABSTRACT

Two grain rotations, winter wheat-barley-fallow and continuous wheat were studied from 1983 to 1985 at two sites, Lethbridge (Chernozemic loam) and Vauxhall (Chernozemic clay loam) in semi-arid southern Alberta. Three rates of broadcast $^{15}NH_4NO_3$ were applied to microplots (1 m^2) which were superimposed on conventional (CT) and no-till (NT) treatments for each crop.

Greater yields for NT than CT grain crops were associated with greater surface soil (0-75 mm) moisture levels in NT than CT treatments.

Crop yield and crop N concentration increases with greater increments of fertilizer N were most often observed in NT compared to CT treatments for spring seeded crops when conditions promoted N immobilization. Fertilizer N immobilization was promoted by increased soil moisture and high C/N crop residue.

A greater imbalance between crop production and organic matter decomposition in NT than CT treatments resulted in greater soil organic matter content in NT than CT soil in the continuous wheat rotation.

Greater amounts of soil water were conserved by NT compared to CT plots on a Lethbridge loam soil but not on a Chin clay loam. Variation in soil moisture conservation between NT and CT for the two soil types was attributed to differences in mulch layer thickness and textural layers.

Larger biomass in CT than NT treatments in the spring was related to higher soil temperatures in CT treatments for spring seeded crops and to greater soil moisture in CT treatment for winter wheat. Improved soil moisture and larger biomass growth in NT than CT soil appeared to be caused by greater amounts of surface crop residue in the NT treatment.

Based on crop yields and long-term soil quality, NT was a superior tillage system than CT for this semi-arid region. Seedbed preparation tillage should be avoided, if possible, and fertilizer placements used that minimize soil disturbance to avoid loss of surface soil moisture. Fertilizer N placed below the crop residue layer would be effective in minimizing fertilizer N immobilization.

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1. INTRODUCTION

Classification of soils according to their suitability for no-till farming has proven to be difficult because many different factors relating to site, weather, and soil properties are involved. Early research studies with reduced tillage systems were concerned with obvious problems such as seedbed preparation, soil moisture conservation, drainage, and soil compaction. More recently, properties such as soil temperature, soil organic matter, and processes like fertilizer N uptake and soil N transformations have been studied under various tillage systems.

In areas of abundant precipitation, problems often occur with residue management, weed control, seed placement, soil fertility, disease, and insects (Papendick and Miller, 1977). Loss of soil fertility was attributed to greater N immobilization, leaching, and/or denitrification. Advantages of no-tillage (NT) have been better erosion control, moisture conservation, and increased surface organic matter (Lindwall and Anderson, 1977; Unger et al., 1971).

In areas of low growing season precipitation such as the semi-arid prairies of Canada and the U.S.A., the performance of both no-till or conventional till (CT) has been unpredictable. Although better yields under no-till are often attributed to greater soil water storage (Lindwall and Anderson, 1977; Unger et al., 1971), in southern Alberta, on a sandy soil, less total soil water was conserved under no-till (Lindwall et al., 1984). Hammel et al. (1981) reported that under certain conditions some tillage may be necessary for retention of adequate seed-zone water for early fall establishment of winter wheat.

Aggregate size distributions in the surface soil can differ widely between tillage systems (Allmaras et al., 1965) and has been correlated with plant yield (Taylor and Johnson, 1956). Lindwall (1983) reported that the aggregate size distribution of the top 5 cm of soil was quite different between tillage systems prior to seeding and was further affected by the planting operation. Hadas (1970) showed that soil aggregates should be less than one-fifth the size of the seed to ensure good seed-soil water contact. Håkansson and Polgár (1984) found that for small cereal grains under dry weather conditions seed should be covered by a 4-5 cm loose soil layer consisting of aggregates <4 mm. Heinonen (1979) discussed the advantages of stratified soil layers and crop residue mulching in reducing evaporation from soil.

In a field study in southern Alberta, smaller yields on both chemical fallow and NT stubble, compared to conventional fallow and CT stubble, respectively, were attributed to smaller amounts of NO_3-N (Lindwall et al., 1984). Larger NT compared to CT yields were usually found at low N fertilizer rates or without added N (Bandel et al., 1975; Moschler et al., 1972).

Labelled fertilizer ^{15}N studies have shown that fertilizer N recovery with NT was favored over CT treatments in years with little growing season precipitation (Legg et al., 1979). Kitur et al. (1984) found less fertilizer N uptake by grain and smaller yields for NT compared to CT and attributed less uptake to increased immobilization of N at the soil surface. In a study where large amounts of straw were added to the soil Fredrickson et al. (1982) reported that grain fertilizer-N uptake was greater for NT but no differences in yield occurred between tillage systems. Decreased total fertilizer-N recovery for NT was attributed to soil surface immobilization. A study by Aulakh et al. (1984) using large amounts of straw found that fertilizer N immobilization was much greater for CT. In a semi-arid region, Carter and Rennie (1984b) found no difference in wheat yields between tillage systems and changes in tillage did not markedly affect the soil N cycle.

Under a semi-arid environment, soil temperatures differences between tillage treatments affected early plant growth but did not influence final grain yields (Carter and Rennie, 1985a). Corn yields were reduced under NT and correlated with decreased soil temperatures in the subhumid region of southern Manitoba (Wall and Stobbe, 1983).

A growth chamber study with a loam soil demonstrated that bulk densities over 1.25 Mg m^{-3} with soil moisture near field capacity were necessary to adversely affect plant growth (Lindwall, 1983). In a field study in southern Alberta encompassing six locations, the average bulk density (1.06 Mg m^{-3}, 0-50 mm layer) was not affected by tillage (Lindwall et al., 1984). Shrinking and swelling characteristics of soils can prevent increased bulk densities and decreased porosities under NT (Cannell et al., 1978).

Only a few studies have measured the response of microbial biomass to different tillage systems. Lynch and Panting (1980) found that increased soil biomass under NT was related to a greater density of plant roots than under CT. Soil microbial biomass plays an important role in soil N transformations. Biomass can compete with crops for fertilizer N and soil N and can also release this N later in the growing season. This can have a profound effect on crop response to fertilizer N and the final yield. Carter and Rennie (1984a) found that microbial biomass N increased with the development of the rhizosphere during the growing season for both CT and NT but differences in biomass N between tillage systems was positively correlated to the amount of surface crop residue. After chemical fallow there were large amounts of crop residue in the surface soil compared to conventional fallow.

Long-term rotations have greater labile organic matter in the 0-50 mm soil layer for NT but greater amounts in the 50-100 mm soil layer for CT (Carter and Rennie, 1982). However, variations in biomass N size and in immobilization of fertilizer N did not affect plant uptake of N or final grain N content or yield (Carter and Rennie, 1985b). A study with crop rotations showed that biomass size was affected mainly by soil moisture and soil moisture changes, and to a lesser extent by temperature, change in temperature, crop growth index, and freeze-thaw cycles (McGill et al., 1986). Tillage and crop residue additions were not closely related to biomass variability. Tillage probably affected biomass C through its effect on soil moisture and soil moisture change. Campbell and Biederbeck (1976) found that microbial change was directly proportional to moisture change. Carter and Rennie (1984a) predicted that widely fluctuating moisture and temperature conditions at the soil surface could produce conditions that would favor rapid N mineralization from microbial biomass. This process could be greatly affected by tillage system.

In many of the field research studies previously described greater moisture conserved with NT compared to CT produced yield and N transformation differences between tillage systems. Greater moisture can directly benefit crop growth or, conversely, it can be detrimental through its effect on inorganic N leaching. Greater moisture can also interact with greater amounts of surface crop residue in NT to reduce available soil N by causing greater immobilization and denitrification losses of soil and fertilizer N. More soil moisture combined with greater surface residues can reduce soil temperature for the NT system compared to the CT system, particularly early in the growing season.

Comparison of tillage systems in the semi-arid region of the Canadian prairies did not show major changes between tillage systems in moisture conservation, soil temperature, or in the soil N cycle (Carter and Rennie, 1984b, 1985a, 1985b). As a result, changes in crop yield and crop N uptake and response to fertilizer N were not observed as they were in more humid areas. Carter and Rennie (1985b) suggested that major differences between tillage systems in crop yield, fertilizer N uptake, and soil N transformations would not occur unless reduced tillage was combined with methods to conserve overwinter precipitation or unless the systems were compared under greater amounts of crop residues. This recent work in the Western Canadian Prairies indicates that more information is required in semi-arid regions on the effect of tillage system on crop yield, fertilizer N uptake, and soil N cycle under crop rotations which produce different amounts of crop residue. The combination of greater crop residue along with the conservation practices of NT could modify the results found in previous studies for this semi-arid area. The amount and timing of precipitation during the growing season could affect results for tillage studies in semi-arid areas. Field studies under different climatic conditions would be necessary to test this effect.

The general objective of this study was: 1) to determine the influence of tillage treatment on crop yield, crop N uptake, and soil N transformations under several soil, crop rotation, and weather conditions; 2) to measure soil parameters over several years under a variety of cropping and soil conditions to identify and characterize those tillage induced soil changes which determine the relative benefits of two tillage systems; 3) to determine the effect of tillage treatment on microbial growth and immobilization of fertilizer N. The crop rotations produced a wide range in amount of crop residue and the study was carried out over three growing seasons characterized by very different precipitation levels. The main hypotheses of this thesis were:

(1) Tillage induced soil moisture changes directly affect final crop yield.

(2) Tillage induced changes in soil moisture, soil temperature, and soil residue affect the soil N cycle and indirectly affect crop N uptake and final crop yield.

(3) Tillage effects on crop yield and the soil N cycle alters the equilibrium level of soil organic matter and affect long-term soil quality.

The results from the three areas of study were reported in three chapters. The titles and objectives for these chapters are as follows:

Chapter 2. Yield and recovery of ^{15}N-labelled fertilizer N for barley and wheat under two tillage systems in southern Alberta.

Objectives: To determine the influence of tillage treatment on soil N transformations and crop N uptake and crop yield responses to fertilizer N, under several soil, crop rotation, and climate conditions.

Chapter 3. Effects of tillage induced soil changes on plant growth and soil quality in a semi-arid region.

Objectives:
1) To measure soil parameters over several years under a variety of cropping and soil conditions.
2) To identify and characterize those tillage induced soil changes which determine the relative benefits of the two tillage systems.

Chapter 4. Biomass growth and microbial N immobilization with broadcast ^{15}N ammonium nitrate in a grain crop rotation under two tillage systems.

Objectives:
1) To determine the effect of tillage treatment on biomass growth and immobilization of broadcast ^{15}N ammonium nitrate.
2) To determine the effect of any tillage-induced soil changes in temperature, moisture, crop residue level, and/or inorganic N on biomass growth.

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2. YIELD AND RECOVERY OF ^{15}N-LABELLED FERTILIZER N FOR BARLEY AND WHEAT UNDER TWO TILLAGE SYSTEMS IN SOUTHERN ALBERTA[1]

2.1 INTRODUCTION

Nitrogen (N) experiments carried out in western Canada and the United States have shown lower grain yields with no-till (NT) compared to those with conventional tillage (CT) systems at low N levels. At high N application rates the grain yields the NT systems were similar or superior to CT systems (Stobbe, 1979; Blevins et al., 1977; Moschler et al., 1972). In southern Saskatchewan, crop yield responses to broadcast NH_4NO_3 were similar for CT and NT (Carter, 1982). In seasons of low growing season precipitation, N availability for crops under NT was reduced relative to CT because of lower mineralization and/or increased fertilizer immobilization (Kitur et al., 1984; Fredrickson et al., 1982). Under moist conditions, nitrate leaching and denitrification were greater on NT soils (Aulakh et al., 1984; Groffman, 1984; Linn and Doran, 1984). More residues with NT increased denitrification by increasing surface soil moisture and providing an energy source for microbial activity (Aulakh et al., 1984). Plant uptake of fertilizer N was higher with CT at low N rates but greater with NT at high N rates in a corn silage study (Legg et al., 1979). In a continuous cropping study with spring wheat, fertilizer N uptake was higher with NT even at low rates (Fredrickson et al., 1982; Moschler et al., 1972). Greater N uptake was favored by higher soil moisture conditions in NT.

[1] A version of this chapter will be submitted for publication. Carefoot, J. M., Nyborg, M. and Lindwall, C. W. 1987. Can. J. Soil Sci.

In another study, fertilizer N uptake and concentration in grain was higher for NT than for CT in dry years (Legg et al., 1979). In wet seasons, N uptake of corn was higher with CT than with NT. Less fertilizer N uptake by NT corn was attributed to denitrification, macro-pore leaching, and/or immobilization (Meisinger et al., 1985).

Potential losses of ammonia by volatilization from urea and ammonium nitrate was higher for NT soils (Touchton and Hargrove, 1982; Carter, 1982). With NH_4NO_3 broadcast on the surface, there was increased immobilization of N at the surface of the NT soil compared to CT (Kitur et al., 1984). Doran (1980) suggested that fertilizer management practices should reflect the increased potential for immobilization of surface applied N for NT compared to CT.

Immobilization of fertilizer N was greater under CT than with NT (Aulakh et al., 1984) in which broadcast N was washed into the soil. Denitrification was greater for NT soils with broadcast ammonium fertilizers (Meisinger et al., 1985; Aulakh et al., 1984). In many studies the surface soil has a greater water content with NT than with CT treatments (Gauer et al., 1982; Phillips et al., 1980).

Adequate spring surface soil moisture is especially critical in semi-arid climates for adequate germination and early growth. Work at Lethbridge has shown that the soil moisture loss associated with spring tillage required for banding fertilizer N prior to seeding can reduce crop yields (Carefoot, 1982). In semi-arid regions under conditions of limiting moisture NT often conserves more surface soil moisture but the potential effects of this additional moisture on crop yield are often unpredictable. Is this additional soil moisture directly used by the crop or does this moisture facilitate fertilizer or soil N uptake? Can additional soil moisture also reduce crop growth by increasing denitrification, immobilization, volatilization, or leaching of N? In southern Alberta where moisture is often limiting and potential evapotranspiration rates are very high, identifying the soil and cropping conditions under which NT produces additional surface soil moisture compared to CT is essential. How this additional moisture affects crop yield and N losses for the highly variable climatic conditions of southern Alberta is also very important.

Crop rotation can affect the soil N cycle in several ways. Residues from previous crops directly affect soil surface moisture (Phillips et al., 1980). The amount, C/N ratio, and N content of residue is very important in processes such as denitrification (Aulakh et al., 1984) and mineralization/immobilization (Wagger et al., 1985). Understanding the effect of tillage on soil N transformation processes will assist in identifying superior fertilizer placement and crop rotation practices.

This study was carried out with grain crops under CT and NT in rotations with different types and quantities of crop residue on two soil types. The objective of this study was to determine the influence of tillage treatment on soil N transformations, crop N uptake, and crop yield responses to fertilizer N under several soil, crop rotation, and climatic conditions.

2.2 MATERIALS AND METHODS

Field experiments were initiated in 1976 at Lethbridge on a Lethbridge loam and at Vauxhall (in 1980) on a Chin clay loam (Table 2.1, Appendix 6.5) (Carefoot and Lindwall, 1982). Two crop rotations were used: 1) winter wheat-barley-fallow (WBF); 2) continuous spring wheat (CW). Two tillage treatments, conventional till (CT) and no-till (NT) were imposed on each crop treatment. A split-plot design with five replicates was used with the crop (or fallow) as main plots and the two tillage treatments as sub-plots (6x40 m). In 1983 and 1984 three N levels were superimposed as sub-sub-plots (1x1 m) on the crop tillage sub-plots to create a split-split-plot design. In 1985, three N levels were superimposed on the tillage sub-plots (1x1 m) for winter wheat and barley. The continuous wheat, winter wheat, and barley sub-sub-plots that were fertilized in 1984 were continued as continuous wheat, barley, and fallow sub-sub-plots, respectively, in 1985 and were referred to as residual fertilizer N sub-sub-plots.

Table 2.1. Some characteristics of the soils (0-150 mm layer)

	Lethbridge loam	Chin clay loam
Canadian Classification	Dark Brown Chernozemic	Brown Chernozemic
U.S.A. Classification	Typic Haploboroll	Typic Haploboroll
Duration of experiment (y)	10	5
pH	7.1	6.6
Organic matter (g kg^{-1})	22.4	17.1
Total N (g kg^{-1})	1.5	1.2
Bulk density (Mg m^{-3})	1.25	1.29
Moisture at 33 kPa (g kg^{-1})	212	191

The same experimental design, but with six replicates, was used at the Vauxhall site in 1984.

Initial seedbed preparation on the CT sub-plots and the CT summerfallow was done with a heavy-duty cultivator with rod weeder. The final seedbed preparation was done with a rod weeder and packer combination. Winter wheat (Triticum aestivum L. cv. Norstar), spring wheat (Triticum aestivum L. cv. Chester), and barley (Hordeum vulgare L. cv. Galt) was seeded using a 3-rank hoe drill with 200-mm row spacing and 20-mm wide furrow openers.

On the NT fallows, atrazine (0.7 kg/ha) was applied after harvest to provide weed control through part of the summerfallow season. For the remainder of the summerfallow season and just before seeding of winter wheat, paraquat was applied (1:1-dimethyl-4,4-bipyridium) at 0.56-0.84 kg/ha with 2,4-D (ester of (2,4-dichloro phenoxy) acetic acid).

at 0.56 kg/ha or with glyphosate (N-(phosphonomethyl)glycine) at 0.46 kg/ha.

Ammonium nitrate with a ^{15}N content of 4.9895 (% atom abundance) in 1983 and 1984, was dissolved in 500 ml of H_2O and sprayed on 1-m^2 plots at N rates equivalent to 0, 25, and 50 kg ha^{-1} to barley (WBF rotation) and wheat (CW rotation) immediately after seeding. Lower N rates equivalent to 0, 15, and 30 kg ha^{-1} were used for winter wheat as less N was required by a crop after fallow.

Each sub-sub-plot was sampled to a depth of 1200 mm in 75-mm increments in the spring before seeding and fall after harvest (see Appendix 6.1). Soil samples were mixed, stored at 5°C and extracted within 2 days. Plant counts were taken 3 weeks after seeding for three one-metre row segments. In 1983 and 1984, top growth and roots were removed from the whole portion of the 1 m^2 plots in the fall. The roots harvested came out of the soil when the grain was pulled out. In 1985, the central portion of the 1 m^2 plots (0.7 m x 0.7 m) was harvested separately from the rest of the plot. Grain samples were threshed while the straw and roots were combined in one sample. Plant samples were dried at 65°C and ground to pass through a 1-mm sieve.

The soil moisture content was determined gravimetrically. Ammonium-N and NO_3^--N was determined by extraction with 2M KCl and steam distillation into boric acid (Bremner, 1965). Samples containing <0.5 mg of N were spiked with 1 mg of NH_4^+-N as analytical grade $(NH_4)_2SO_4$ to facilitate accurate measurement of ^{15}N content. Soil samples were analyzed for total N using a pre-digestion treatment of $KMnO_4$ and ferrous iron to convert NO_2^--N or NO_3^--N to NH_4^+-N (Bremner, 1965). All distillates were evaporated at 65°C and the N^{15}/N^{14} contents were determined on a VG Micromass SIRA12 mass spectrometer. Percent N derived from fertilizer (%NDFF) in plant and soil was calculated as follows:

$$\text{Plant \%NDFF} = \frac{\text{N \% excess (plant)}}{\text{N \% excess (fertilizer N)}} \times 100$$

$$\text{Total Fertilizer N in plant (kg ha}^{-1}) = \frac{\text{\%NDFF}}{100} \times \text{plant yield (kg ha}^{-1}) \times \frac{\text{\% N}}{100} \text{ in plant}$$

$$\text{Soil \% NDFF} = \frac{\text{N \% excess (soil)}}{\text{N \% excess (fertilizer N)}} \times 100$$

$$\text{Total Fertilizer N in soil (kg ha}^{-1}) = \frac{\text{\%NDFF}}{100} \times \text{bulk density (Mg m}^{-3}) \times \text{volume of soil (m}^{3}\text{ha}^{-1}) \times \frac{\text{\% N}}{100} \text{ in soil}$$

^{15}N natural abundance values were obtained by analyzing soil and plant samples in two control replicates.

Analysis of variance was based on a split-split-plot design (Little and Hills, 1978).

2.3 RESULTS

2.3.1 Seasonal Precipitation and Soil Moisture

The three years of this study were characterized by different amounts of precipitation and soil moisture deficit during the growing

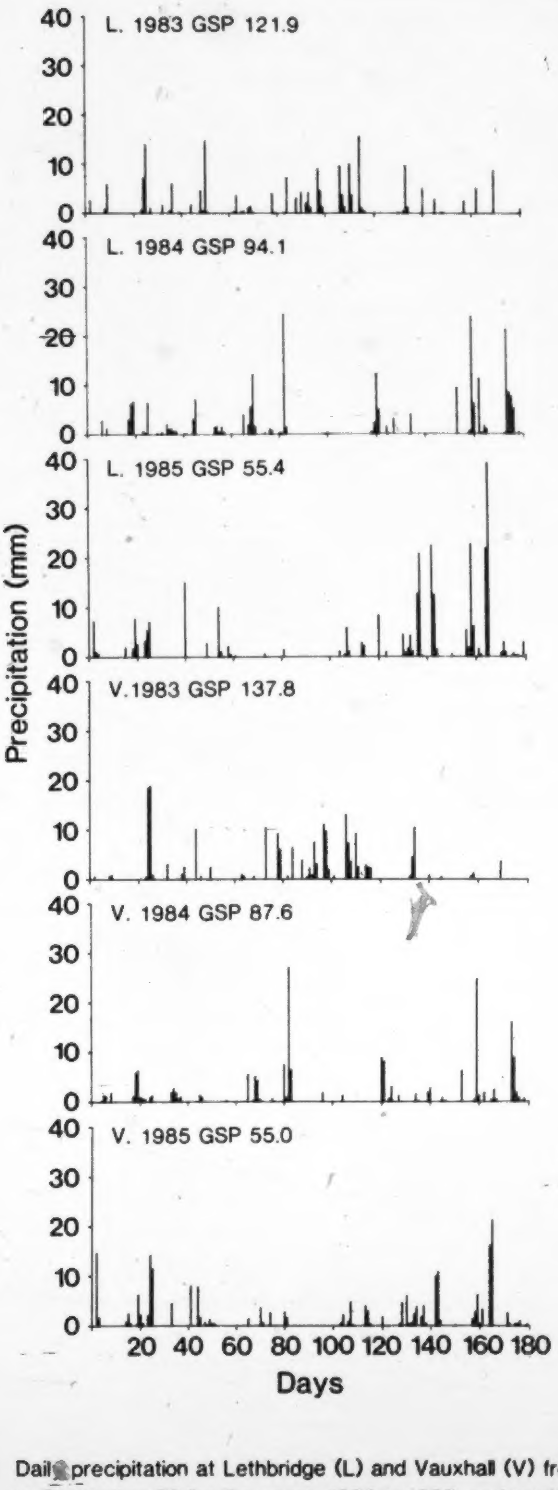

Fig. 2.1 Daily precipitation at Lethbridge (L) and Vauxhall (V) from April 1 to September 20 for the years 1983 to1985, and total growing season precipitation (GSP mm) from May 1 to July 31.

season (Fig. 2.1). For the critical growing season months of May, June, and July the amount of precipitation for 1983, 1984, and 1985 at Lethbridge were 121.9, 94.1, and 55.4 mm, respectively (long-term average is 94.1 mm). The amount and timing of precipitation was similar at both sites. When soil conditions were drier in the spring and the fall, soil moisture tended to be higher with NT than with the CT treatments (Table 2.2). At mid-season, soil moisture levels were generally similar for tillage treatments.

Table 2.2. Surface soil moisture during the growing season in NT and CT for winter wheat, barley, and spring wheat

		May		July		Sept	
		CT	NT	CT	NT	CT	NT
Lethbridge soil water content (mm) (0-75 mm layer)							
Winter wheat	1983	18.2	19.6	7.7	7.3	8.2	11.0*
	1984	13.3	14.2	7.3	3.2*	7.1	8.7*
	1985	17.6	18.7	8.3	9.0	13.9	14.3
Barley	1983	18.3	18.9	8.2	8.1	5.3	6.1
	1984	14.7	16.6*	4.6	3.8	8.0	7.9
	1985	18.3	18.9	9.3	8.5	14.8	14.9
Spring wheat	1984	12.6	16.6*	6.8*	4.0	8.6	7.8
Vauxhall soil water content (mm) (0-75 mm layer)							
Winter wheat	1984	10.5	12.1*	3.5	2.7	4.4	5.4*
Spring wheat	1984	8.6	10.6*	2.9	2.8	3.8	5.7*

*Tillage systems significantly different (P = 0.05) for a particular month.

2.3.2 Grain and Straw Yields

Winter wheat grain yields (Table 2.3) averaged 1710 kg ha^{-1} for the two tillage treatments on the clay loam soil at Vauxhall in 1984. In contrast to the grain yield, the straw yield was greater with NT. At the Lethbridge site on the loam soil, grain and straw yields were greater with NT every year. Fertilizer nitrogen resulted in no yield increases with winter wheat at either site.

Table 2.3. Winter wheat: Grain and straw yields at three N levels under CT and NT

			Grain				Straw			
			N rate kg ha^{-1}				N rate kg ha^{-1}			
Location	Year	Till	0	15	30	Mean	0	15	30	Mean
			kg ha^{-1}							
Lethbridge	1983	CT	2400*	2480*	2460*	2450*	3590*	3870*	3730*	3730*
		NT	3050	2870	3070	3000	4590	4000	4430	4430
Lethbridge	1984	CT	1550*	1710*	1620*	1630*	2830*	3010*	2770*	2870*
		NT	1800	2020	1950	1920	3500	3640	3550	3560
Lethbridge	1985	CT	970*	1060*	960*	990*	2070*	2350*	2210*	2210*
		NT	1250	1280	1310	1280	2880	2630	2740	2750
Vauxhall	1984	CT	1830	1760	1740	1780	3380*	3250	2980*	3210*
		NT	1730	1560	1620	1640	3710	3310	3460	3500

*Tillage systems significantly different at $P = 0.05$.

Barley grain yield was 440 kg ha^{-1} for NT compared to 240 kg ha^{-1} for CT in 1984 (Table 2.4). Responses to N fertilizer application were observed only in 1983 (grain) and 1985 (straw) in the NT treatment.

There was no effect of tillage or fertilizer on yield on the residual fertilizer N plots.

Table 2.4. Barley: Grain and straw yields at three N levels under CT and NT

			Grain				Straw			
			N rate kg ha^{-1}				N rate kg ha^{-1}			
Location	Year	Till	0	25	50	Mean	0	25	50	Mean
			kg ha^{-1}							
Lethbridge	1983	CT	1450a[†]	1670a	1740a	1620	1050a	1190a	1200a	1140
		NT	1390a	1740ab	1940b	1690	1200a	1270a	1370a	1280
Lethbridge	1984	CT	270a[*]	260a[*]	200a[*]	240[*]	680a[*]	630a[*]	480a[*]	590[*]
		NT	440a	500a	390a	440	870a	1040a	890a	930
Lethbridge	1985	CT	1190a	1040a	1120a	1120	2120a	2940a	2290a	2150
		NT	1010a	1130a	1040a	1060	2180a	2280a	2570b	2350
Lethbridge[‡]	1985	CT	870a	860a	980a	900	2210a	2060a	2150a	2140
		NT	760a	780a	790a	780	1930a	1980a	2030a	1980

[†] Means followed by the same letter within a tillage treatment for grain or straw are not significantly different at $P = 0.05$.

[*] Tillage systems significantly different at $P = 0.05$.

[‡] Residual N plots; fertilized in 1984.

Yields in the continuous wheat rotation were very low (<290 kg ha^{-1}) in 1984 (Table 2.5). At both sites grain and straw yields were greater for NT than for CT. There was no yield response to nitrogen at either site. In 1985, there was a straw yield response to the high fertilizer rate on the residual fertilizer N plots.

Table 2.5. Spring wheat: Grain and straw yields at three N levels under CT and NT

			Grain				Straw			
			N rate kg ha^{-1}				N rate kg ha^{-1}			
Location	Year	Till	0	25	50	Mean	0	25	50	Mean
			kg ha^{-1}							
Lethbridge	1984	CT	40a*†	30a*	30a*	40*	90a*	80a*	80a*	80*
		NT	280a	260a	230a	260	840a	840a	680a	780
Vauxhall	1984	CT	110a*	150a*	120a*	130*	310a*	300a*	290a*	310*
		NT	250a	320a	290a	290	700a	810a	730a	750
Lethbridge‡	1985	CT	930a	910a	870a	900	1990a	2110a	2150a	2080
		NT	780a	700a	780a	750	2050a	2200a	2620b	2290

*Tillage systems significantly different at P = 0.05.

†Means followed by the same letter within a tillage treatment for grain or straw are not significantly different at P=0.05.

‡Residual N plots; fertilized in 1984.

2.3.3 Nitrogen Concentration in Grain and Straw

At the Lethbridge site in 1983, the year of largest crop yields, there was a greater concentration of nitrogen in the winter wheat grain and straw with CT except at the highest N rate of 50 kg/ha (Table 2.6). In 1984 and 1985, the Lethbridge site showed a similar uptake of nitrogen for tillage treatments. Nitrogen concentration in winter wheat grain averaged 27.6 g kg^{-1} for CT and NT at Vauxhall in 1984 while the nitrogen concentration in the straw was 7.4 g kg^{-1} for NT compared to 6.5 g kg^{-1} for CT. In 1983, there was an increase in nitrogen content for barley grain in response to fertilizer application in both tillage treatments (Table 2.7). In 1984, N concentration tended to be greater in CT than in NT. The straw and grain in the NT both showed a response to N application in 1984. There was a N response at the high fertilizer rate for the barley straw in 1985 for both the fertilized plots and the residual N plots.

Table 2.6. Winter wheat: N concentration of grain and straw at three N levels grown under CT and NT

			Grain				Straw			
			N rate kg ha^{-1}				N rate kg ha^{-1}			
Location	Year	Till	0	15	30	Mean	0	15	30	Mean
			g kg^{-1}							
Lethbridge	1983	CT	23.1a*†	23.3a*	22.7a	23.0*	5.8a*	6.3a*	6.5a	6.2*
		NT	20.1a	20.4a	21.9b	20.8	5.2a	5.5a	6.6b	5.7
Lethbridge	1984	CT	23.6a	24.4a	24.9a	24.3	6.1a	6.9a	6.3a	6.4
		NT	23.4a	23.3a	24.7a	23.8	6.3a	6.5a	6.6a	6.4
Lethbridge	1985	CT	30.8a	31.4a	30.8a	31.0	5.8a	6.1a	5.9a	5.9
		NT	30.0a	30.1a	28.6a	29.5	5.7a	5.6a	6.1a	5.8
Vauxhall	1984	CT	27.6a	26.9a	27.3a	27.3	6.5a*	6.4a*	6.7a*	6.5*
		NT	27.5a	28.0a	27.9a	27.8	7.4a	7.5a	7.4a	7.4

*Tillage systems significantly different at P=0.05.

†Means followed by the same letter within a tillage treatment for grain or straw are not significantly different at P = 0.05.

Table 2.7. Barley: N concentration of grain and straw at three N levels grown under CT and NT

			Grain				Straw			
			N rate kg ha^{-1}				N rate kg ha^{-1}			
Location	Year	Till	0	25	50	Mean	0	25	50	Mean
			g kg^{-1}							
Lethbridge	1983	CT	19.9a[†]	21.3b	21.4b	20.8	8.6a[*]	8.7a[*]	9.0a[*]	8.7[*]
		NT	19.0a	19.3a	20.4b	19.6	6.8a	7.4ab	7.9b	7.3
Lethbridge	1984	CT	32.7a[*]	33.4a[*]	32.5a	32.8[*]	17.1a[*]	17.7a[*]	18.3a	17.7[*]
		NT	30.4a	31.0a	32.9b	31.4	13.4a	13.0a	16.7b	14.3
Lethbridge	1985	CT	25.6a	26.2a	25.9a	25.9	7.2a	8.0a	9.8b	8.3
		NT	27.2a	26.7a	26.0a	26.6	7.7a	7.7a	8.4b	7.9
Lethbridge[‡]	1985	CT	29.8a	29.6a	28.8a	29.4	8.3a	9.3b	10.4c	9.3
		NT	28.9a	28.5a	28.0a	28.4	8.3a	8..5a	9.7b	8.8

[†] Means followed by the same letter within a tillage treatment for grain or straw are not significantly different at P = 0.05.

[*] Tillage systems significantly different at P = 0.05.

[‡] Residual N plots; fertilized in 1984.

In the CT treatment at Lethbridge in 1984, the N concentration of the spring wheat grain was 31.1 versus 33.4 g kg^{-1} in the NT treatment (Table 2.8). By contrast, at Vauxhall the N content in grain was less for NT than CT except at the fertilizer rate of 50 kg ha^{-1}. At the 25 kg ha^{-1} fertilizer rate, grain N content was 34.7 g kg^{-1} for CT compared to 32.5 g kg^{-1} for NT. The only response of spring wheat grain N concentration to fertilizer N was in the NT grain treatment in 1984, when the N concentration of the grain increased from 30.4 to 32.9 g kg^{-1} with the addition of 50 kg ha^{-1} of fertilizer N.

Table 2.8. Spring wheat: N concentration of grain and straw at three N levels grown under CT and NT

			Grain				Straw			
			N rate kg ha^{-1}				N rate kg ha^{-1}			
Location	Year	Till	0	25	50	Mean	0	25	50	Mean
			g kg^{-1}							
Lethbridge	1984	CT	31.5a[*,†]	30.8[*]	31.0a[*]	31.1[*]	11.3a[*]	12.8a[*]	12.5a[*]	12.2[*]
		NT	33.4a	33.6a	33.2a	33.4	14.3a	14.5a	14.0a	14.2
Vauxhall	1984	CT	34.5a[*]	34.7a[*]	34.3a	34.5[*]	16.1a[*]	15.3a	14.8a	15.4
		NT	32.4a	32.5a	33.5b	32.8	14.8a	14.6a	15.4a	15.0
Lethbridge[‡]	1985	CT	31.7a	33.4a	32.1a	32.4	6.1a	6.6ab	7.5b	6.7
		NT	34.2a	34.4a	32.9a	33.8	6.4a	6.3a	6.8a	6.5

[*] Tillage systems significantly different at $P = 0.05$.

[†] Means followed by the same letter within a tillage treatment for grain or straw are not significantly different at $P = 0.05$.

[‡] Residual plots; fertilized in 1984.

2.3.4 Labelled Fertilizer N Uptake in Grain

The %NDFF values for the grain were usually greater with NT than with CT (Fig. 2.2). For example, the %NDFF for barley at the high fertilizer N rate in 1983 was 19.7% for CT compared to 30.3% for the NT treatment. With winter wheat there were no differences between tillage treatments in 1984 at either site; and the values were very small (<5.7%) at the Vauxhall site. In 1985 (Fig. 2.3), %NDFF was 7.8% for CT compared to 5.7% for the CT treatment in winter wheat at the 50 kg ha^{-1} fertilizer rate. Likewise, %NDFF was 9.6% for CT compared to 15.4% for the NT treatment in barley. For the residual fertilizer N plots in 1985, there was no effect of tillage treatment on %NDFF values for either grain or straw.

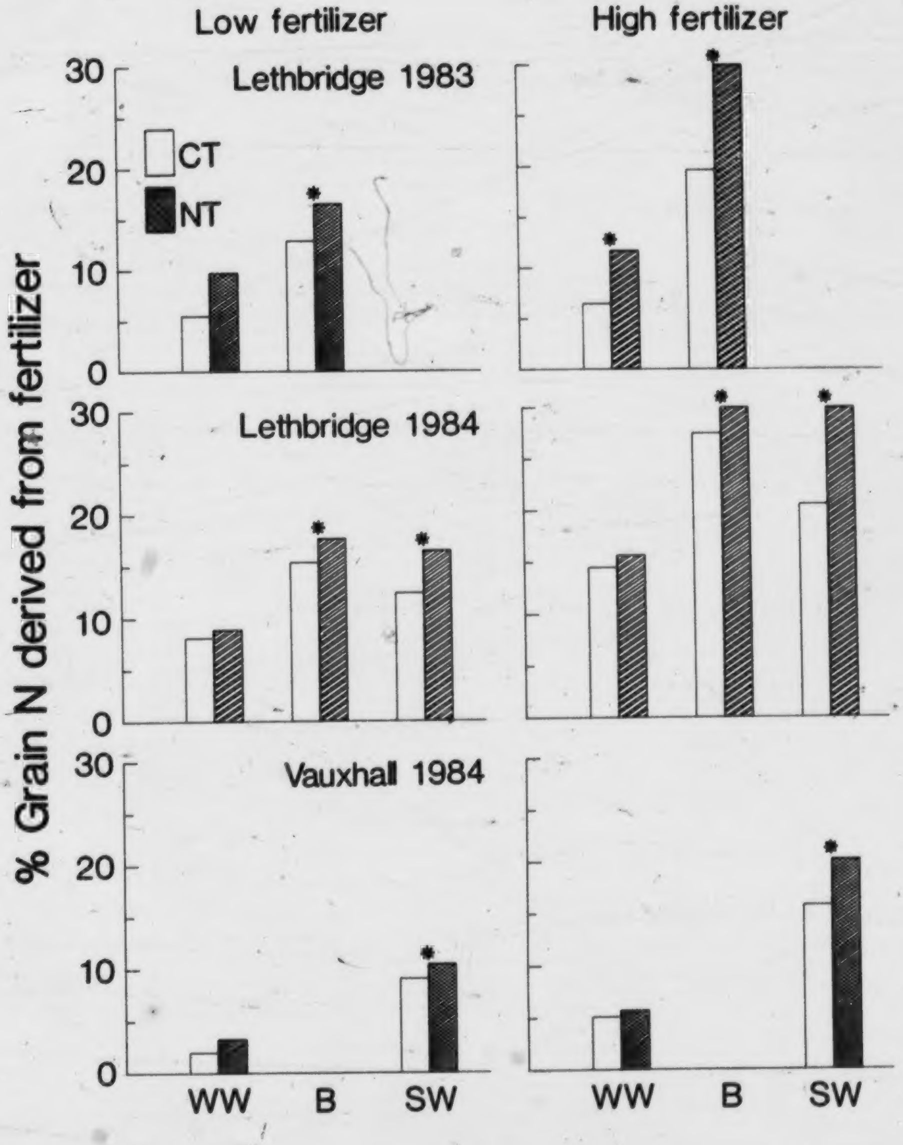

Fig. 2.2 Percent of grain N derived from fertilizer at two fertilizer levels for winter wheat (WW), barley (B), and spring wheat (SW) under CT and NT in 1983 and 1984. (* Tillage systems significantly different at P = 0.05).

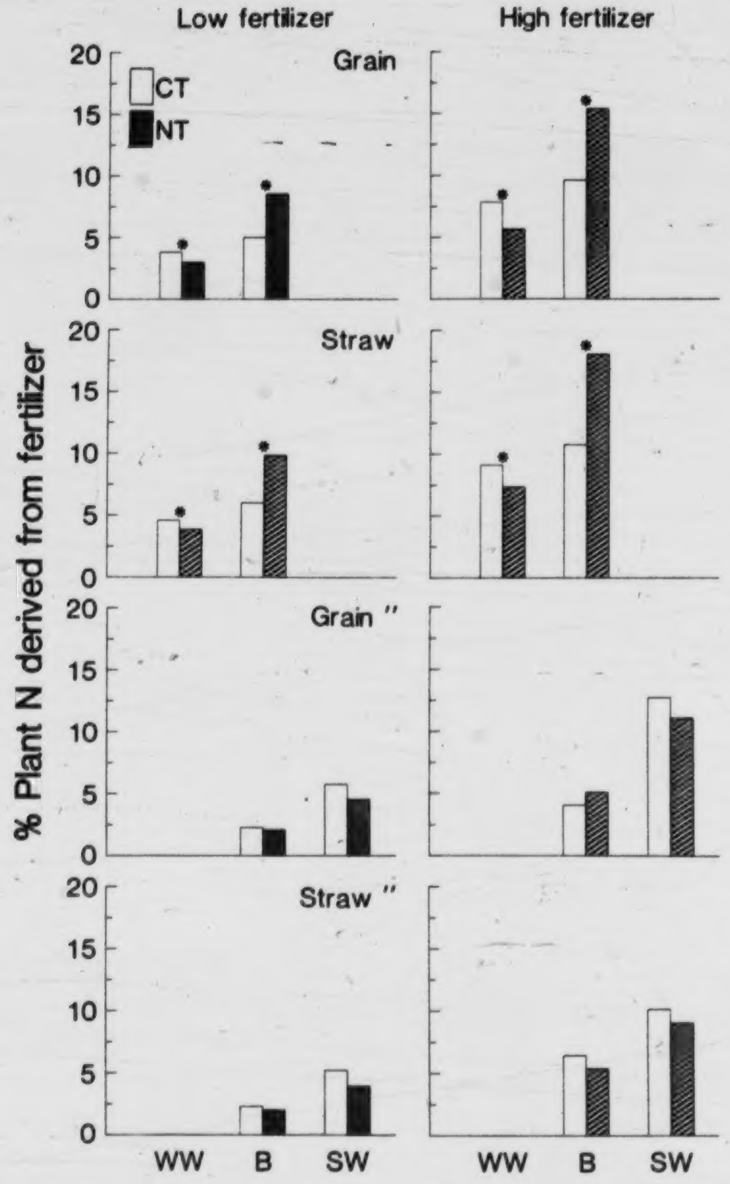

Fig. 2.3 Percent of grain or straw N derived from fertilizer at two fertilizer N levels for winter wheat (WW), barley (B), and spring wheat (SW) under CT and NT in 1985 at Lethbridge. (* Tillage systems significantly different at P = 0.05).

" Residual fertilizer plots fertilized in 1984.

Table 2.9. Distribution of inorganic N in the upper 300 mm of the soil for CT and NT under winter wheat and barley in 1984

Crop	N rate (kg ha^{-1})	Depth (mm)	NH-$_4$N + NO$_3$-N (kg ha^{-1}) Sampling date (month-day) 05-01 CT	05-01 NT	07-15 CT	07-15 NT	08-20 CT	08-20 NT
Barley	0	0- 75	20.2*	12.8	8.1*	3.5	15.4	12.9
		75-150	10.2	12.1	8.6*	3.2	9.5*	4.3
		150-300	3.9*	9.6	5.0	1.5	4.5	2.7
	50	0- 75			17.0*	5.0	24.9*	14.6
		75-150			19.0*	2.4	13.6*	5.4
		150-300			6.9	2.5	6.2	3.4
Winter wheat	0	0- 75	18.4	13.3	3.6	2.9	10.8*	6.3
		75-150	9.5	10.5	6.2	2.0	6.8*	2.2
		150-300	6.9	8.5	1.0	1.3	1.7	.6
	30	0- 75			13.3*	3.8	15.0*	10.7
		75-150			11.1*	1.3	10.7*	3.7
		150-300			2.9	1.1	2.1	.6

*Tillage systems significantly different at $P = 0.05$.

2.3.5 Soil Profile Inorganic Nitrogen (Sub-sub-plots 0-300 mm)

In the spring of 1984, total inorganic N in the soil profiles was similar in the tillage treatments for both barley and winter wheat (Table 2.9). Inorganic N tended to be greater for CT in the 0-75 mm soil layer but greater for NT at the lower soil depths. By mid-season inorganic N was much less for NT than CT at both fertilizer rates for barley. For winter wheat a difference was only evident at the high fertilizer N level. By fall, inorganic N was higher for CT at both fertilizer rates and for both crops. Inorganic N in the soil profiles was not affected by tillage treatment during the crop seasons of 1983 and 1985 (data not shown).

2.3.6 Surface Inorganic Nitrogen (Sub-plots 0-75 mm)

Inorganic N in the top soil layer (0-75 mm) (Fig. 2.4) in 1983 at Lethbridge was generally not affected by tillage treatment except for spring wheat treatment at Lethbridge in 1983, where inorganic N was greater (Fig. 2.5) for the CT compared to the NT treatment for 3 out of 5 sampling dates.

In 1984, after precipitation events at mid-season, greater inorganic N occurred in CT than NT treatments for all crops at Lethbridge. At Vauxhall, inorganic N differences occurred between tillage treatments, but the pattern was inconsistent.

There was no difference in mineral N on fallow plots at either site.

2.3.7 Labelled Inorganic and Organic Soil N

In 1984, most of the recovered fertilizer N was concentrated in the top 150 mm of soil with the CT treatment and in the top 75 mm of soil with the NT treatment (Table 2.10). In 1985, the fertilizer N was concentrated in the top 75 mm of soil for both tillage treatments. In 1984, 12.67 kg ha^{-1} of fertilizer N was immobilized in the organic N fraction (0-75 mm) with NT compared to 3.93 kg ha^{-1} with the CT treatment for barley, while for winter wheat in 1984 fertilizer N immobilization was 6.88 ka hg^{-1} in the NT treatment compared to 3.33 kg ha^{-1} in the CT treatment. In 1985, for winter wheat, 7.14 kg ha^{-1} of fertilizer was immobilized in the CT treatment (0-75mm) but only 4.14 kg ha^{-1} in the NT treatment.

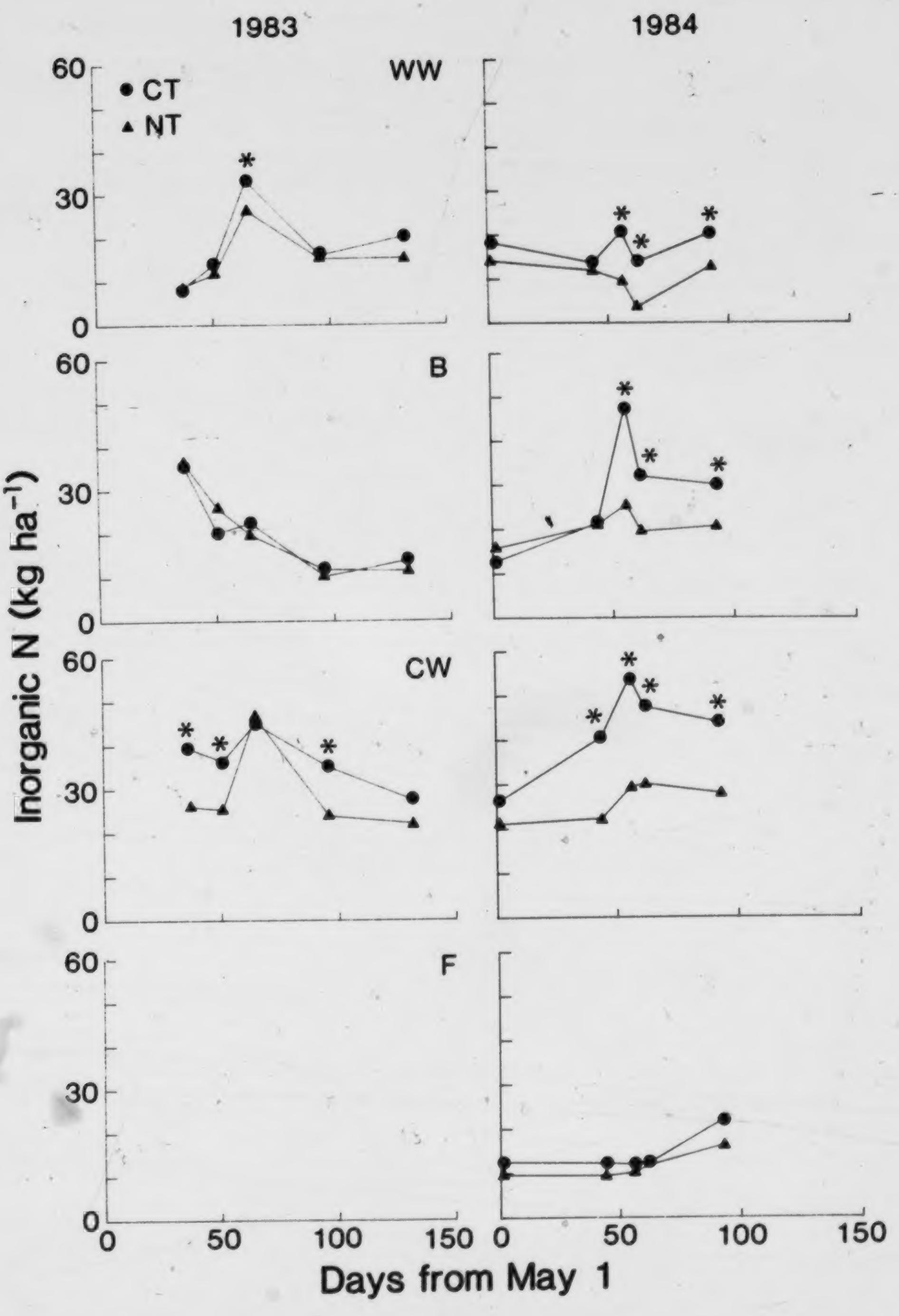

Fig. 2.4 Soil inorganic N for the 0-75 mm soil layer from May 1 to October for crops and fallow under CT and NT at Lethbridge in 1983 and 1984. (* Tillage systems significantly different at P = 0.05).

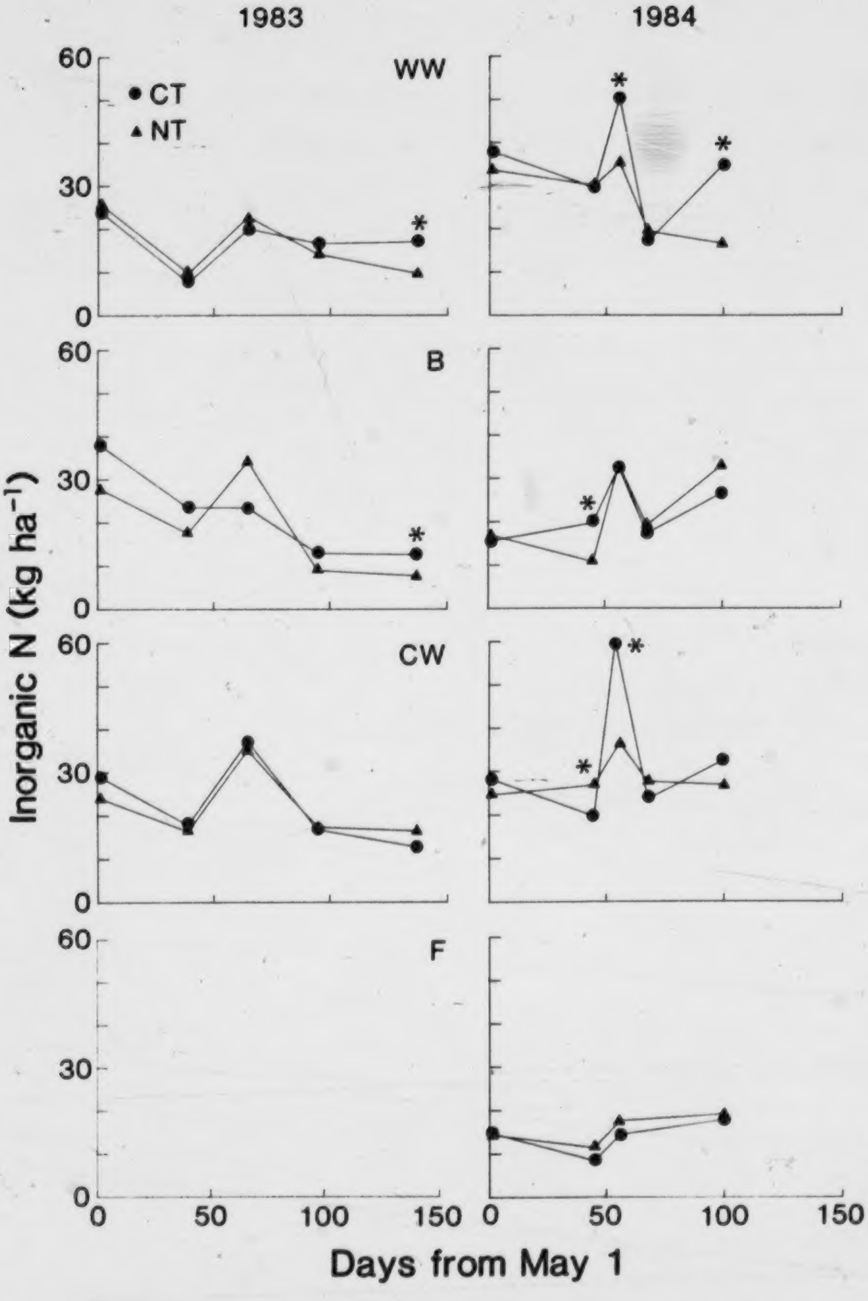

Fig. 2.5 Soil inorganic N for the 0–75 mm soil layer from May 1 to October for crops and fallow under CT and NT at Vauxhall in 1983 and 1984. (* Tillage systems significantly different at P = 0.05).

Table 2.10. Labelled fertilizer N recovery (kg ha^{-1}) in different fractions in the soil profiles for winter wheat and barley under CT and NT in 1984 and 1985 at mid-season[†]

Crop	N rate (kg ha^{-1})	Depth (mm)	Inorganic N		Organic N		Total N	
			CT	NT	CT	NT	CT	NT
1984								
Winter wheat	30	0- 75	2.41	0.13[*]	3.33	6.88[*]	5.74	7.01
		75-150	1.77	0.08[*]	1.63	3.32[*]	3.40	1.46[*]
		150-300	0.09	0.03	1.62	1.35	1.68	1.38
Barley	50	0- 75	4.41	0.85[*]	3.93	12.67[*]	8.34	13.52[*]
		75-150	6.51	0.28[*]	2.36	1.71	8.87	1.99[*]
		150-300	0.85	0.17	2.51	3.06	3.36	3.23
1985								
Winter wheat	30	0- 75	6.81	9.81	7.14	4.14[*]	13.95	14.32
		75-150	1.59	1.08	1.06	1.10	2.65	2.18
		150-300	0.22	0.22	2.51	2.68	2.73	2.90
Barley	50	0- 75	11.51	9.01	10.74	12.00	22.25	21.01
		75-150	1.10	1.03	0.73	1.20	1.83	2.23
		150-300	0.26	0.21	2.51	2.14	2.77	2.35

[†] Sampling dates: 1984-06-15 and 1985-06-03.

[*] Tillage systems significantly different at $P = 0.05$.

Table 2.11. Winter wheat at Lethbridge: Labelled fertilizer N recovery[†] in grain, straw, and soil with CT and NT

			Fertilizer N recovery (%)			
Year	Till	N rate (kg ha^{-1})	Grain	Straw	Soil	Total
1983	CT	15	21.1	9.6	35.1	65.8
	NT	15	25.2	8.0	37.5	70.7
	CT	30	18.2[*]	4.7	22.3	45.2
	NT	30	26.2	6.0	21.8	53.4
1984	CT	15	22.1[*]	9.0[*]	36.3	67.4
	NT	15	27.0	11.7	35.1	73.8
	CT	30	19.1[*]	6.8[*]	37.0	62.9
	NT	30	24.9	10.2	37.1	72.2
1985	CT	30	7.7	3.9	66.0	77.6
	NT	30	7.0	4.1	72.8	83.9

[†] Fertilizer N recovered (g)/N rate (g) x 100.

[*] Tillage systems significantly different at $P = 0.05$.

Table 2.12. Barley at Lethbridge: Labelled fertilizer N recovery[†] in grain, straw, and soil with CT and NT

		N rate	Fertilizer N recovery (%)			
Site	Till	(kg ha^{-1})	Grain	Straw	Soil	Total
1983	CT	25	17.8[*]	4.7	27.2[*]	49.7
	NT	25	21.7	6.0	21.6	49.3
	CT	50	13.3[*]	3.6[*]	25.6	43.5[*]
	NT	50	23.9	6.1	25.1	55.1
1984	CT	25	5.5[*]	7.4[*]	46.5[*]	59.4
	NT	25	10.8	10.0	32.3	53.1
	CT	50	3.5[*]	5.1[*]	39.7[*]	48.3
	NT	50	7.9	9.1	34.8	51.8
1985	CT	50	5.5	4.5	63.6	73.6
	NT	50	8.7	7.4	56.1	72.2
1985[‡]	CT	30 (14.2)[§]	7.9	10.2	63.1	81.2
	NT	30 (13.8)	9.0	7.5	87.1	103.6

[†] (Fertilizer N (g)/N rate (g))100.

[*] Tillage systems significantly different at $P = 0.05$.

[‡] Residual N plots.

[§] Residual fertilizer N recovered (total soil N) in spring of 1985 from sub-sub-plots fertilized in the spring of 1984.

Table 2.13. Spring wheat at Lethbridge: Labelled fertilizer N recovery[†] in grain, straw, and soil with CT and NT

Site	Till	N rate (kg ha^{-1})	Fertilizer N recovery (%)			
			Grain	Straw	Soil	Total
1984	CT	25	0.5[*]	0.6[*]	60.0	61.1
	NT	25	5.9	8.5	51.4	65.8
	CT	50	0.4[*]	0.5[*]	49.1	50.0
	NT	50	4.8	6.0	45.3	56.1
1985[‡]	CT	50 (21.8)[§]	16.3	7.6	62.9	86.8
	NT	50 (21.7)	13.4	7.9	76.4	97.7

[†] (Fertilizer N (g)/N rate (g))100.

[*] Tillage systems significantly different at $P = 0.05$.

[‡] Residual N plots.

[§] Residual fertilizer N recovered (total soil N) in spring of 1985 from sub-sub-plots.

2.3.8 Recovery of Labelled Fertilizer N

Total recovery of fertilizer N ranged from a low of 43.6% for barley in CT in 1983 to a high of 83.9% for the NT winter wheat treatment in the very dry year of 1985 (Tables 2.11, 2.12, 2.13). Generally, there were no differences in total fertilizer N recovery between tillage treatments. Greater recovery of fertilizer N in the NT crop, usually due to a combination of higher yields and fertilizer N concentration in the crop, was balanced by a lower soil recovery. Recovery of residual fertilizer N, measured in the spring as total N, was 100.7% with NT and 84.0% for CT.

2.4 DISCUSSION

The results were discussed according to two cropping sequences: fall-seeded winter wheat, which comes after fallow, and spring wheat and barley which followed a crop. Results for individual years were discussed because of different effects of growing season precipitation on crop yield, crop fertilizer N uptake, and soil N transformations. The years 1983, 1984, and 1985 were classified as wet (above average), dry (average), and very dry (below average), respectively. These are relative terms and in comparison to a humid region, all three years received low levels of growing season precipitation.

2.4.1 Winter Wheat After Fallow

Less winter wheat grain and straw yields for CT compared to NT treatments were not related to a reduced mineral N supply. Comparable, or greater amounts of inorganic N occurred in CT than NT treatments (Table 2.9). Greater crop yields with NT than with CT were often associated with greater surface soil water (0-75 mm) in the spring. Seedbed soil moisture was below average for September sown winter wheat in all three years. Low precipitation in the fall combined with Chinook winds and tillage resulted in a relatively dry seedbed for the CT treatments. In a previous study (Carefoot and Lindwall, 1982) greater yields with NT than with CT crops were associated with low precipitation during the early part of the growing season. The relative importance of total soil water and surface soil water to crop yield will be reported elsewhere (Chapter 3).

Nitrogen concentrations in the winter wheat grain were not affected by tillage treatment in 1984 and 1985. In 1983, smaller N concentrations in the NT winter wheat grain at the lower fertilizer N rates can be attributed to the effect of tillage treatment on fertilizer N immobilization. Fertilizer N immobilization was affected by crop, tillage, and precipitation timing. Conventional fallow (Lindwall and Anderson, 1981) and crop residue incorporation (Christensen, 1986) increased the rate of straw decomposition with CT compared to the NT treatment. Fertilizer N immobilization was favored by greater amounts of crop residue coinciding with the washing of broadcast fertilizer N into the surface soil layer (0-75 mm). In 1983 and 1984, precipitation occurred later in the growing season. Thus, greater crop residue with NT than with CT treatments later in the growing season apparently caused greater fertilizer N immobilization as indicated by crop N response, crop N content, and soil N measurements. For example, barley N concentration was 32.7 g kg^{-1} in CT and 30.4 g ka^{-1} in the NT check treatments. The NT treatment showed an increase in grain N concentration from 30.4 to 32.9 g kg^{-1} with 50 kg ha^{-1} of fertilizer N while there was no fertilizer response in the equivalent CT treatments. Soil inorganic N (0-75mm) was 47.6 kg ha^{-1} in the NT compared to 25.1 kg ha^{-1} in the CT treatments in 1984 at mid-season (Fig. 2.4).

The 1985 growing season was characterized by good early moisture but minimal precipitation for the rest of the growing season. A better stand of winter wheat with NT than with CT resulted in more rapid depletion of the surface soil moisture and caused the surface crop residue to dry quickly. With CT, greater soil water content combined with incorporation of crop residue by tillage, favored fertilizer N immobilization in CT than NT treatments (7.14 vs. 4.14 kg ha^{-1}, respectively) (Table 2.10). Variation in fertilizer N immobilization between tillage treatments did not result in different crop yields or grain N contents.

The %NDFF in winter wheat between tillage treatments varied each year. In winter wheat, surface soil moisture was depleted quickly by the crop and this masked any tillage effect on moisture content. Usually, better early crop growth under NT depleted soil moisture more than with CT, especially in a dry year. In 1983, with June rains, %NDFF values were greater with NT than with CT in spite of more fertilizer N immobilization in the NT than the CT treatments. In 1984 there was no tillage effect on %NDFF values at either site (Fig. 2.2). This was plausible because the soil remained very dry until July in both tillage treatments. Greater %NDFF for CT in 1985 reflected better surface soil moisture in the spring. At the high fertilizer rate %NDFF was 7.83% for CT compared to 5.66% for NT. Since no significant precipitation occurred during the summer, this difference favoring CT winter wheat continued through the growing season. %NDFF in plants did not reflect the %NDFF of soil mineral N reported elsewhere (Chapter 4, Fig. 4.2). The occurrence of greater %NDFF in plants with greater surface soil moisture suggests that with poor surface soil moisture plant roots used a deeper source of soil N with less ^{15}N activity.

This study indicated that fertilizer N immobilization was greater for the NT than for the CT treatments when significant precipitation occurred during the growing season. In a very dry growing season, banding fertilizer N below the residue layer could prove to be a superior fertilizer placement technique, providing steps are taken to minimize overwinter losses (Mahli and Nyborg, 1985).

2.4.2 Spring Wheat and Barley After a Crop

Comparable or greater amounts of inorganic N with CT than with NT treatments, as well as a lack of response to fertilizer N in CT spring-seeded crops, suggests that the decreased yields for CT encountered in this study were not caused by a reduced N supply. Greater yields for NT than for CT spring-seeded crops in 1984, a year with low surface soil moisture at seeding time, supports previous findings (Carefoot and Lindwall, 1982).

Fertilizer N immobilization affected N concentration of barley crops and, to a lesser degree, spring wheat. Spring wheat yields were small and soil mineral N was abundant. Good soil moisture conditions at seeding time in 1985 favored similar amounts of fertilizer N immobilization in different tillage treatments (Table 2.10) but small yields and abundant mineral N prevented a response to fertilizer N. Early June rains in 1983 moved fertilizer N into the surface soil (0-75 mm) where crop residue would be less decomposed in the NT treatment than in the CT treatment. Barley grain N concentration was increased by fertilizer N at a lower increment in the CT than the NT treatment. In 1984, greater crop residue in the NT treatment (Christensen, 1986) combined with good soil moisture in late July resulted in fertilizer N immobilization of 12.67 kg ha^{-1} in the NT compared to 3.93 kg ha^{-1} in the CT treatment (Table 2.10), and subsequently, an increase in barley N concentration with the highest rate of fertilizer N (Table 2.7). Mineral N was much less in NT barley treatments by mid-season in 1984 (Table 2.9). At the 50 kg ha^{-1} fertilizer rate inorganic N (0-75 mm) was 17.0 kg ha^{-1} for CT compared to 5.0 kg ha^{-1} for the NT treatment.

The %NDFF values (Figs. 2.2 and 2.3) in grain and straw were greater with NT than with CT crops at both sites. The %NDFF in barley grain was 31.6% for the NT compared to 27.5% in the CT treatment. Similarly in spring wheat, %NDFF was 30.1% for the NT compared to 20.6% for the CT treatment. This could be a result of less mineralized soil N in the NT treatment. Mineralization of soil N is often greater with CT than with NT during the growing season (Meisinger et al., 1985; Skinner et al., 1963; Rice and Smith, 1982). More %NDFF in the mineral N fraction for CT than NT treatments (Chapter 4, Fig. 4.2) indicates that dilution by soil inorganic N is not the main reason for this crop uptake difference. Greater %NDFF values for NT appeared to have been partly related to surface soil moisture. For spring crops, greater soil moisture with NT allowed faster nitrification of fertilizer N and more movement into the soil (Rice and Smith, 1983). Greater densities of plant roots near the soil surface with direct drilling have been reported (Lynch and Panting, 1980) and if associated with greater fertilizer ^{15}N activities could result in higher %NDFF values than would be the case with roots using a deeper source of N. Dry soil surface conditions in CT treatments would strand broadcast fertilizer N on the soil surface and plant roots would use a deeper source of soil N.

Greater yields with NT compared to CT spring-seeded crops showed the benefits of NT systems. Increased immobilization of broadcast fertilizer N in NT treatments indicated that banding fertilizer N below the residue layer could often be beneficial. Previous studies indicated that under dry conditions the banding operation can reduce final yields when the fertilizer placement was carried out prior to or during the seeding operation (Carefoot, 1982). The best fertilizer placement may be a method such as point injection that minimizes disturbance of the seedbed while at the same time reducing immobilization by putting fertilizer below the crop residue layer.

2.4.3 Residual N Plots

Barley and spring wheat yields and crop N concentrations were not affected by tillage treatment on the residual N plots in 1985. Similar %NDFF values for the tillage treatments for straw and grain of barley and spring wheat indicates that there were no major differences in residual fertilizer N availability.

2.4.4 Total Fertilizer N Recovery

The largest percent fertilizer N recovery of 83.9 in the crop plus soil occurred for winter wheat in 1985, the driest growing season (Tables 2.11 and 2.12). Part of the reason for greater recoveries in 1985 may have been that a central portion of the 1 m^2 microplot, from which there would be minimal loss of fertilizer N to outside plants, was harvested separately. In 1983 and 1984, because of poor plant stands, the whole 1 m^2 microplot was harvested as one sample. Because some fertilizer N would have been lost to outside plants, the total N recovery was reduced but recovery comparisons between tillage systems should still be valid. Even when crop stands were poor and apparently little fertilizer N was lost to plants outside the microplot, total fertilizer N recoveries were far from complete. Low fertilizer N recoveries have been attributed to denitrification (Rice and Smith, 1982; Aulakh et al., 1984) and/or leaching (Meisinger et al., 1985;

Thomas et al., 1973; Carter and Rennie, 1985). During the three years of the study there was no evidence of fertilizer N movement below 600 mm. Short, intense rains occurred during the summers of 1983 and 1984 and with fertilizer N concentrated in the surface soil, conditions existed for denitrification. Cho et al. (1979) predicted that maximum denitrification would occur in mid-summer when soil temperatures were highest.

Significant N losses may have occurred as NH_3 volatilization. Conditions of low initial moisture, low humidity, high winds, broadcast fertilizer, high temperatures, low soil CEC, and alkaline pH at the Lethbridge site, would favor this type of loss (Terman, 1979). Fenn and Kissel (1974) found volatilization losses of up to 25% from suface broadcast NH_4NO_3.

Bole and Gould (1986) noted a high ^{15}N recovery (average of 86%) for experiments in southern Alberta with spring application of urea on barley, but the fertilizer was incorporated into the top 10 cm of soil.

Another pathway for N loss could be volatilization from plant material during the growing season. Losses are greatest with high temperatures and plants with high concentrations of nitrogen (Wetselaar and Farquhar, 1980). These conditions prevailed during the dry growing season of this study, but losses as reported by Wetselaar and Farquhar (1980), when measured directly, have generally been quite small compared to the amount applied. In 1984, the spring wheat crop at Lethbridge was very poor but fertilizer N recoveries of ^{15}N-labelled fertilizer N were still low. This suggests that the main loss mechanisms were soil related. Total fertilizer N recoveries varied little with tillage treatment. Although this field study was not designed to quantitatively assess losses via each pathway, it does suggest that the amount and pathway of fertilizer N losses were similar for tillage systems. Banding fertilizer N rather than broadcasting would probably have reduced the N losses incurred in this study.

2.5 CONCLUSIONS

Greater yields for NT than CT grain crops were associated with greater surface soil moisture levels in NT treatments particularly when dry soil conditions were prevalent in the early part of the growing season. Based on crop yields, NT compared to CT appeared to be a superior tillage system for this semi-arid region.

The effect of residual fertilizer N from the previous crop season on crop yield and grain N concentration was similar in CT and NT treatments.

Increases in crop yield and crop N concentration with increasing rates of fertilizer N were most often observed in NT spring seeded crops, when conditions promoted N immobilization. Fertilizer N immobilization was favored by greater soil moisture and crop residue in the NT than the CT treatments. Greater fertilizer N immobilization for NT compared to CT treatments suggested that fertilizer N should be placed below the crop residue layer to minimize fertilizer N immobilization. With spring application of ^{15}N-labelled broadcast NH_4NO_3, the recovery in the crop and soil at harvest was relatively low (minimum of 44%) for a semi-arid region.

Total fertilizer N recovery was inversely related to growing season precipitation. Nitrogen losses were similar for tillage treatments and were attributed to volatilization and denitrification. The %NDFF grain values were generally greater for NT than for CT crops, apparently due to increased soil surface moisture.

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3. EFFECTS OF TILLAGE INDUCED SOIL CHANGES ON PLANT GROWTH AND SOIL QUALITY IN A SEMI-ARID REGION[1]

3.1 INTRODUCTION

Field studies have shown that tillage induced soil changes often have varied effects on crop yield depending upon factors such as climate, crop, rotation duration, and soil characteristics.

Lower soil temperatures in NT corn have been shown to delay emergence and reduce grain yield (Wall and Stobbe, 1983). Carter and Rennie (1985) found lower temperatures under NT spring wheat in the early part of the growing season but the final yield was not affected. Temperature differences up to 5^{0}C between NT and CT did not affect the N cycle but were a factor in plant growth (Rennie and Heimo, 1984). Removal of crop residue from the area immediately above the seed resulted in higher soil temperatures and improved early growth of corn (Lindwall, 1983).

Cereal grain yields obtained using NT methods were higher than those obtained using conventional tillage on medium- and fine-textured soils but not on coarse-textured soils (Dryden and Bowren, 1969). On coarse-textured soils, reduced root distribution was related to greater bulk density or reduced pore size under NT (Ellis et al., 1977; Finney and Knight, 1973). On fine-textured soil there was greater root concentration at depth under NT compared to plowed conditions (Hodgson et al., 1977). The deeper rooting of NT winter wheat facilitates greater moisture extraction from depth and may result in yield increases (Goss et al., 1978; Cannell et al., 1980). Shrinking and swelling characteristics of fine-textured soils can prevent high bulk densities and low porosities (Cannell et al., 1978). Bulk densities exceeding 1.25 Mg m^{-3} at intermediate and high initial soil moisture contents caused poor plant growth but had no effect at low soil moisture contents (Lindwall, 1983).

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[1] A version of this chapter will be submitted for publication. Carefoot, J. M., Nyborg, M., and Lindwall, C. W. 1987. Can. J. Soil Sci.

A surface mulch can reduce evaporation early in the growing season and increase soil moisture (Phillips, 1980). More residue under NT spring seeded crops cause lower surface soil temperatures due to a greater coefficient of reflectance (Hanks et al., 1961) and therefore less evaporation (Blevins et al., 1971). Carter (1982) related improved soil moisture regimes (0-5 cm) under NT to differences in surface residue between the tillage systems although there were no differences in total soil water conserved. In the same study, water use from deeper in the soil was enhanced at the long-term NT sites but there was no difference in yield between tillage systems. Long-term studies at a Lethbridge site showed that chemical fallow conserved more moisture and produced higher yields than conventional fallow (Lindwall and Anderson, 1981). In shorter term studies (5 yr), at six locations in southern Alberta, NT did not increase soil moisture conservation or bulk density relative to CT (Lindwall et al., 1984). At one sandy site, moisture conservation was better under CT. Other studies have shown that better pore continuity to lower soil depths under NT can allow for greater moisture losses (Phillips, 1980; Darwent and Bailey, 1981). On chemical fallow some shallow tillage may be necessary for conservation of soil water (Hammel et al., 1981; Tanaka, 1985). Tillage may only be necessary for sandy soils or soils just introduced to NT where there is little residue or soil organic matter buildup in the soil surface horizon. Shallow tillage reduces evaporative losses by disrupting pore continuity and impeding upward movement of soil water (Tanaka, 1985).

Lower yields at some locations in southern Alberta for chemical fallow relative to conventional fallow were attributed to lower NO_3^--N levels (Lindwall et al., 1984). Uptake of N by direct-drilled crops is often slower in the earlier stages of growth (Cannell and Graham, 1979).

Slower mineralization of N from soil organic matter occurred under no-till (Dowdell and Cannell, 1975). No-till crops are often more N deficient and this has been related to immobilization of fertilizer N at the soil surface (Rice and Smith, 1984; Kitur et al., 1984). Slower residue decomposition with minimum till due to less mixing and drying on the soil surface can produce greater immobilization of both soil and fertilizer N later in the growing season (Meisinger et al., 1985). Webster et al. (1985) attributed greater absorption of fertilizer NO_3^--N applied later in the growing season by NT than CT barley to less soil NO_3^--N. When straw residue was mixed with the soil for CT, immobilization of ^{15}N fertilizer N was greater than for NT (Aulakh et al., 1984; Tomar and Soper, 1985). With greater soil moisture enhanced denitrification (Aulakh et al., 1984; Rice and Smith, 1982) and greater leaching losses (Tyler and Thomas,1977; Carter and Rennie, 1985) occurred in NT soils.

Different concentration gradients in the surface soil have been reported for several nutrients for NT compared to CT. Greater organic

N, P, and C concentrations occurred in the Ap soil horizon but less in the 150- to 300-mm depth for NT after 18 years (Dick, 1983). Drew and Saker (1980) reported greater extractable P and K in the surface soil for NT. More nutrients in the NT soil surface as well as greater root densities and greater soil moisture favored nutrient uptake for NT corn crops (Singh et al., 1966). Hargrove (1985) showed that the uptake of a tracer, Rb (which simulates K), was larger under NT due to greater density of roots and better soil moisture.

Potential microbial biomass, as defined by Carter and Rennie (1982) is the biomass after a one-week incubation at 80% of the available soil water capacity and 25°C. Potential microbial biomass and net mineralizable C and N were greater in the surface soil under NT but were greater for CT from the 150-300 mm soil layer (Carter and Rennie, 1982). There are few reports of differing nutrient concentration gradients in NT and CT soil resulting in significant differences in crop yield.

A recent study at several locations in the semi-arid region of Western Canada did not show marked tillage effects on crop yield or soil N transformations (Carter and Rennie, 1984b). Carter and Rennie (1984b) felt that field studies featuring a wide range of crop residue levels and different soil water conservation practices could modify previous results.

The previous studies indicate that many tillage-induced changes in soil parameters can affect crop yield and crop N concentration, but it has not been clear which changes will become important for a given set of conditions. Researchers and producers in southern Alberta require information on how crop growth is affected by tillage system for different crop rotations, amounts of crop residue, soil types, and weather conditions. This information would assist in making recommendations regarding tillage practices.

It is hypothesized that, in the semi-arid region of southern Alberta when growing season precipitation is well below average, improved soil moisture conservation under NT than CT will improve crop growth. The amount of additional soil moisture conserved with NT compared to CT will be affected by crop rotation and soil type.

The above hypotheses were tested by measuring soil parameters over several years for different crop rotations and soil types to determine under which crop, weather, and soil conditions NT compared to CT will conserve more soil moisture and improve crop growth.

3.2 MATERIALS AND METHODS

The main field experiments were located at Lethbridge (initiated in 1976) on a Lethbridge loam and at Vauxhall (initiated in 1980) on a Chin clay loam. The two grain rotations used in this study were: 1) winter wheat-barley-fallow (W-B-F); 2) continuous spring wheat (CW). Characteristics of the two soils and detailed precipitation data were reported elsewhere (Chaper 2). Growing season precipitation was 121.9 mm in 1983 and 94.1 mm in 1984 at Lethbridge and 137.8 mm in 1983 and 87.6 mm in 1984 at Vauxhall. The long-term average for growing season precipitation at Lethbridge and Vauxhall is 94.1 mm and 95.6 mm respectively.

The three crops and one fallow for 1983 and 1984 each included two tillage treatments: 1) cultivated; 2) no-till. A split-plot design with five replicates was used, the three crops and fallow as main plots and the two tillage treatments as subplots (6 x 40 m). This gave a total of 5 x 4 x 2 = 40 subplots. A similar experimental design was used at the Vauxhall site in 1984 with six replicates and 6 x 4 x 2 = 48 subplots. The initial seedbed preparation on the tilled subplots and tilled summerfallow was done with a heavy-duty cultivator. The final seedbed preparation was done with a rod weeder and packer combination. In 1983, barley and spring wheat were seeded on May 12 at Lethbridge and May 25 at Vauxhall. In 1984, barley and spring wheat were seeded on May 8 at Lethbridge and May 15 at Vauxhall. Chemicals used in this study were previously described in detail (Carefoot and Lindwall, 1982). Crops were seeded with a 3-rank hoe drill with 200-mm row spacing and 20 mm wide furrow openers.

Ammonium nitrate was broadcast on both tillage treatments before seeding, at a N rate of 50 kg ha^{-1} for barley in the 3-yr rotation and for continuous wheat. Similarly, N at 30 kg ha^{-1} was broadcast in the spring for winter wheat in the 3-yr rotation.

3.2.1 Sampling

Subplots were sampled to a depth of 1200 mm in 75-mm increments in the spring and the fall of 1983 and 1984 (Appendix 6.1). Every 2 to 3 weeks the subplots were sampled to 300 mm in 75-mm increments. Soil samples were mixed and stored at 5^oC, and NH_4^+N and NO_3^-N was extracted with KCl (2 mol L^{-1})within 2 days. Plant emergence counts were taken

3 weeks after seeding. Plant samples (3 x 1 m) were taken from each subplot at the first visible node stage. Plant samples were dried at 65°C and ground to pass through a 1-mm sieve. Final yields were based on a combine-harvested mass from a sample area of 3 x 40 m.

Soil temperature (°C) was measured bi-weekly at soil depths of 20, 100, 350, 400, 600, and 900 mm. Biweekly temperature readings were taken using copper-constantan thermocouples at 830 and 1600 hr.

3.2.2 Sample Analysis

Bulk densities were calculated from the mass of soil in each core increment (25 mm (d) x 75 mm (l)). Soil moisture was determined gravimetrically. Inorganic nitrogen, NH_4^+-N and NO_3^--N, was determined by extraction with 2M KCl and distillation into boric acid (Bremner, 1965). Plant and soil samples were analyzed for total N using modified macro-Kjeldahl procedures, and soil samples from the spring sampling were analyzed for organic C by dichromate oxidation (Bremner, 1965).

Rainfall and evaporation data were obtained from agrometeorology sites at each location.

3.2.3 Statistics

Analysis of variance was based on a split-plot design (Reps Crops/Tillage). Standard errors for testing effects of the factors applied to main plots and subplots and their interactions were calculated as described by Little and Hills (1978). Linear correlation analyses were used to examine the relationship between grain yield and the soil and plant properties.

3.3 RESULTS

3.3.1 Soil Temperature

Spring soil temperature for the barley treatment (Table 3.1) averaged 13.9°C in the NT compared to 14.7°C in the CT treatment, but the difference between tillage treatments was not evident later in the season. For wheat, soil temperature differences between tillage treatments generally occurred after harvest. At this time, soil temperatures were lower in the NT treatments. Tillage effects on soil temperature were small, 0.5 to 2.0°C compared to between-year effects.

Table 3.1. Average monthly soil temperatures[†] in CT and NT in 1983 and 1984 at the Lethbridge site

		Continuous wheat		3-yr rot. winter wheat		3-yr rot. barley	
Month	Year	CT	NT	CT	NT	CT	NT
		°C					
May	1983	15.5	15.0	13.3	14.8*	16.0	15.0*
	1984	13.0	13.0	13.3	12.7*	13.3	12.7*
June	1983	17.6	16.6	16.4	15.8	17.2	17.4
	1984	19.3	19.7	19.3	17.3	19.0	18.3
July	1983	19.0	19.5	18.0	19.0	18.0	18.5
	1984	25.0	22.6*	25.0	24.2	23.4	23.8
August	1983	22.0	21.0	23.0	21.[illegible]	22.1	22.0
	1984	23.0	21.0*	22.0	21.0*	22.0	22.2

[†] °C at the 10-cm soil depth at 830 hr.

*Tillage systems significantly different (P = 0.05).

3.3.2 Soil Bulk Density

Soil bulk densities taken after harvest did not differ between tillage treatments across crop rotations. Bulk densities for the Lethbridge and Vauxhall soils were 1.25 and 1.29 Mg m^{-3}, respectively, for the 0-150 mm soil layer (average values for both crop rotations in 1983 and 1984) (Appendix 6.3).

3.3.3 Soil Water (0-75 mm)

In the NT wheat crops there was more soil water in the top soil layer from July until October, 1983 at Lethbridge (Fig. 3.1). In the fall of 1983, there was more soil water in the NT treatments for all crops. There were no soil water differences between tillage treatments during the fallow season. In 1984, which had a very dry spring, soil water conditions were generally better under the NT treatment. There were no soil water differences between tillage treatments in the fall of 1984 except for fallow which was sown to winter wheat.

At Vauxhall in 1983 (Fig. 3.2) soil water content was not affected by tillage treatment except for barley in the spring where the soil water content was less with NT than CT (5.3 vs 6.5 mm, respectively) because of excessive volunteer weed growth that was not adequately controlled. In the dry year of 1984, soil water was 12.1 mm for the NT compared to 10.5 mm for the CT wheat treatment in the spring but there was no tillage effect for the barley plots which were not yet planted. The same situation occurred in the fall. Throughout the 1984 season the soil water was less in the NT fallow treatment. Total soil water (to 1200 mm) at Lethbridge (Table 3.2) was greater for all NT treatments in the spring. Usually the soil water differences between

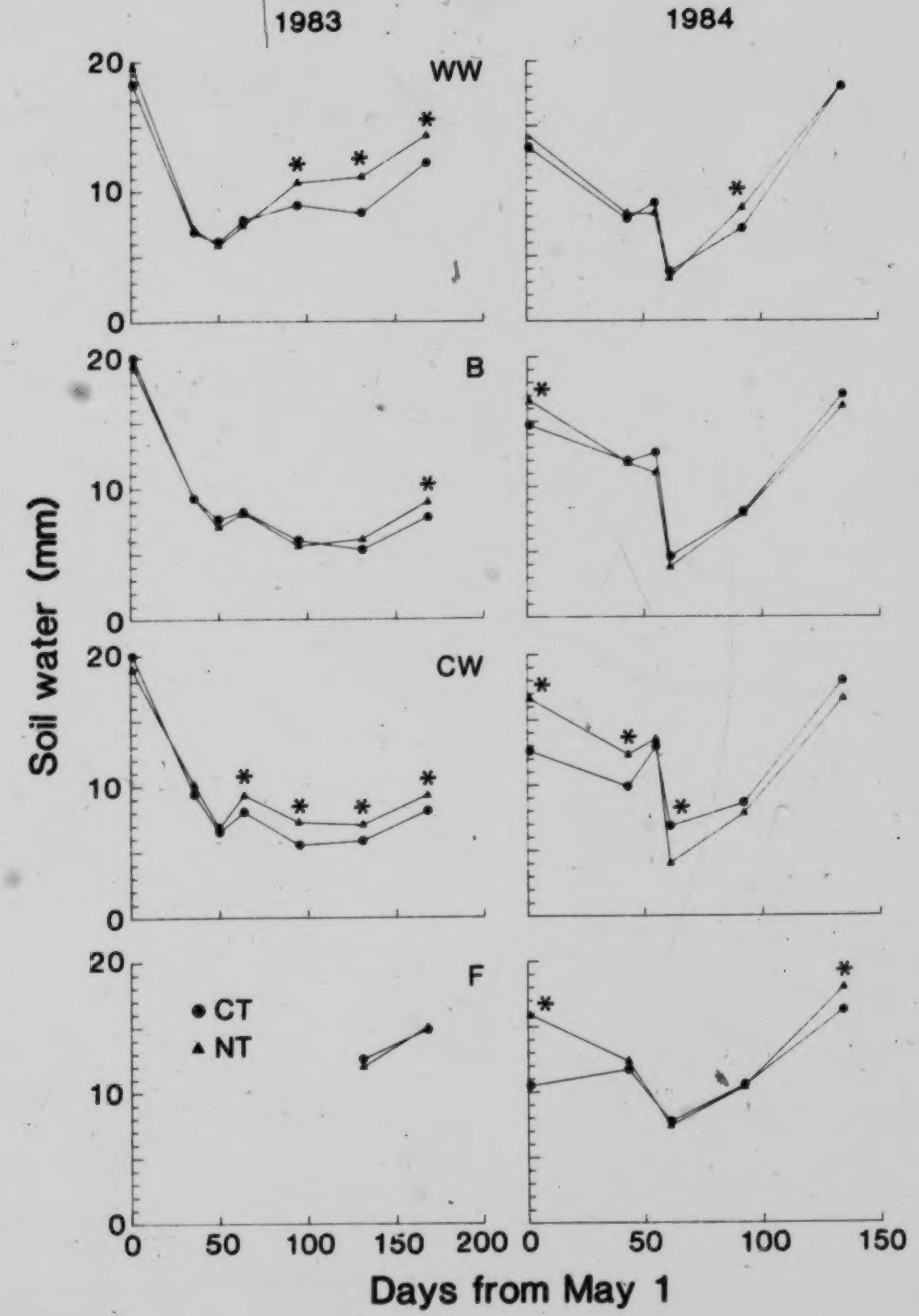

Fig. 3.1 Soil water for the 0-75 mm soil layer from May 1 to October for crops and fallow under CT and NT at Lethbridge in 1983 and 1984. (*Tillage systems significantly different at P=0.05).

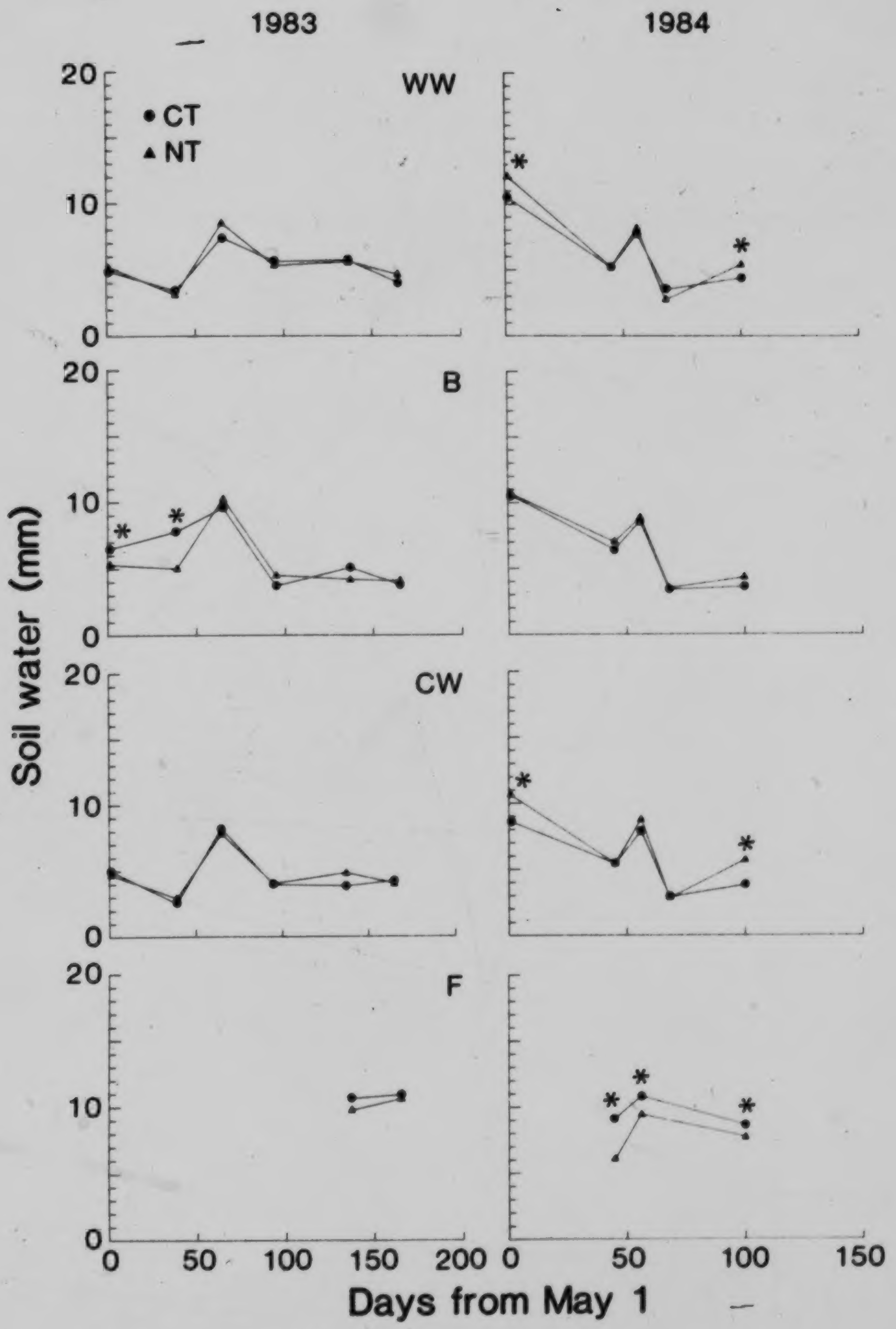

Fig. 3.2 Soil water for the 0-75 mm soil layer from May 1 to October for crops and fallow under CT and NT at Vauxhall in 1983 and 1984. (*Tillage systems significantly different at P = 0.05).

tillage treatments was in the top 30 cm. but for winter wheat the soil water differences were apparent at greater depths.

Table 3.2. Total soil water in the spring and fall for CT and NT at the Lethbridge site in 1984

Season	Soil depth (mm)	Continuous wheat		3-yr wheat		3-yr barley		Fallow	
		CT	NT	CT	NT	CT	NT	CT	NT
		Total water (mm)							
Spring	0- 300	38.3	60.9*	52.0	56.2	46.9	60.8*	36.5	55.1*
	300-1200	101.7	107.8	139.6	155.4*	98.7	97.7	87.5	102.1*
	0-1200	138.0	160.4	183.5	213.9*	140.4	157.0*	134.0	157.2*
Fall	0- 300	40.0	33.5	29.9	32.4	34.7	31.6	48.2	52.8
	300-1200	100.9	99.6	94.7	89.6	95.2	91.8	105.0	117.1*
	0-1200	140.8	133.1	134.6	121.9	129.9	123.4	153.2	169.9

*Tillage systems significantly different (P = 0.05).

Relative soil moisture changes (Table 3.3) between tillage treatments for the various seasons revealed that the major difference in soil water change occurred during the winter period. Soil moisture was also lost in the fall period of the 3-yr CT winter wheat where seedbed preparation was necessary for seeding the winter wheat crop. In the fall period for 3-yr winter wheat 34.9 mm of water was gained in the NT treatment compared to only 11.7 mm for the CT treatment.

Table 3.3. Total soil water change (0-1200 mm) during different seasons for CT and NT at the Lethbridge site in 1983 and 1984

	Continuous wheat		3-yr winter wheat		3-yr barley		3-yr fallow	
Season	CT	NT	CT	NT	CT	NT	CT	NT
	Total soil water change (mm)							
Spring-early fall	-65.3	-60.3			-63.6	-79.4		
Early-fall-late fall	+46.9	+45.9	+11.7	+34.9*	+46.6	+50.3	+50.9	+59.9
Late fall-spring	-5.9	+9.1*	-10.0	-23.0*	-6.6	+14.2*	-10.5	+17.8*
Spring-early fall			-101.0	-124.8			+10.7	+7.4

*Tillage systems significantly different (P = 0.05).

Total soil water in cropped plots at Vauxhall (Table 3.4) in crops was not affected by tillage treatment except for the continuous wheat treatment where soil water was 134.6 mm for NT compared to 150.1 mm for CT in the 300-1200 mm soil layer.

Table 3.4. Total soil water in the spring and fall for CT and NT at the Vauxhall site in 1984

Season	Soil depth (mm)	Continuous wheat		3-yr winter wheat		3-yr barley		3-yr fallow	
		CT	NT	CT	NT	CT	NT	CT	NT
		Total soil water (mm)							
Spring	0- 300	41.8	46.8	46.8	58.0	47.3	50.0	39.0	40.0
	300-1200	146.2	119.8*	193.3	189.9	136.0	127.5	120.5	112.4
	0-1200	188.0	166.7	250.1	248.0	183.3	177.5	159.7	152.3
Fall	0- 300	25.4	24.7	25.9	27.1	23.2	22.0	45.7	44.2
	300-1200	150.1	134.6*	141.5	142.6	119.5	111.7	167.4	158.5
	0-1200	175.6	159.4	167.4	169.8	142.7	133.8	213.0	202.7

*Tillage systems significantly different (P = 0.05).

3.3.4 Soil Organic Matter and Soil Total Nitrogen

In the continuous wheat rotation (Table 3.5) organic matter was 26.0 g kg^{-1} in the NT compared to 24.3 g kg^{-1} in the CT treatment for the top 75 mm of soil. There was no difference in total N between tillage treatments for any crop.

Table 3.5. Soil organic matter and soil nitrogen content at the Lethbridge site for 1984

Crop	Soil depth (mm)	Organic matter CT	Organic matter NT	Total N CT	Total N NT	Inorganic N Spring CT	Inorganic N Spring NT	Inorganic N Fall CT	Inorganic N Fall NT
		g kg^{-1}				µg g^{-1}			
Continuous wheat	0- 75	24.3	26.0*	1.76	1.81	25.9	19.6*	43.8	27.9*
	75- 150	18.2	20.0	1.40	1.51	9.7	18.0*	34.7	23.7*
	150- 300	15.1	16.0	1.13	1.26	3.0	8.5*	16.1	17.7
	300- 600	11.5	11.8	0.97	0.93	2.4	4.0	2.9	3.9
	600- 900	7.1	6.7	0.65	0.54	3.6	2.9	3.2	2.3
	900-1200	5.2	4.7	0.52	0.46	4.7	2.7	6.8	5.5
3-yr winter wheat	0- 75	23.7	23.8	1.69	1.71	18.4	13.3*	20.4	12.9*
	75- 150	18.9	19.6	1.44	1.51	9.5	10.5	11.0	5.2*
	150- 300	16.7	15.6	1.30	1.29	6.9	8.5	4.0	1.7
	300- 600	11.8	13.6	0.85	0.88	5.5	8.6	2.2	1.5
	600- 900	06.2	06.3	0.54	0.47	3.2	4.7	1.7	1.6
	900-1200	04.7	04.5	0.42	0.44	2.6	3.5	2.8	2.4
3-yr barley	0- 75	24.1	24.3	1.68	1.73	20.2	12.8*	30.0	20.6*
	75- 150	18.4	19.5	1.39	1.45	10.2	12.1	22.1	8.3*
	150- 300	16.3	15.2	1.23	1.37	3.9	9.6*	8.2	5.5*
	300- 600	13.5	11.6	0.84	0.86	4.9	2.6	1.9	2.1
	600- 900	5.6	7.0	0.48	0.49	1.9	1.8	1.6	1.3
	900-1200	4.8	4.9	0.45	0.44	4.5	2.1	3.7	3.8

*Tillage systems significantly different (P = 0.05).

Profiles of inorganic N differed between tillage treatments. In the spring, inorganic N in the NT treatment relative to those in the CT treatment were less in the top 75 mm soil layer but greater in the deeper layers so the total inorganic N was similar for tillage treatments. In the fall, greater amounts of inorganic N in the 0- to 150-mm soil layer for the CT treatment resulted in more inorganic N in the soil profile. For example, the inorganic N (0-75 mm) was 43.8 $\mu g\ g^{-1}$ for CT compared to 27.9 $\mu g\ g^{-1}$ in the NT treatment for continuous wheat.

At the Vauxhall site (Table 3.6), total N was not affected by tillage treatment. As at the previous site, inorganic N in the top 300 mm was similar for the tillage treatments in the spring but greater for the CT treatment in the fall. Below 300 mm, there was abundant (>20 $\mu g\ g^{-1}$) inorganic N in both tillage systems. Inorganic N in the soil profile of the fallow treatment (Table 3.7) in the 3-yr rotation was 22.0 $\mu g\ g^{-1}$ for the CT compared to 16.3 $\mu g\ g^{-1}$ for the NT treatment at the Lethbridge site in the fall. At Vauxhall, there was no inorganic N difference between fallow tillage treatments in the surface soil layers, but inorganic N was greater for CT in the 300-900 mm soil layer in both spring and fall.

Table 3.6. Soil nitrogen content at the Vauxhall site for 1984

Crop	Soil depth (mm)	Total N		Inorganic N			
				Spring		Fall	
		CT	NT	CT	NT	CT	NT
		g kg^{-1}		µg g^{-1}			
Continuous wheat	0- 75	1.24	1.28	28.2	24.7	32.5	26.8*
	75- 150	1.01	1.03	28.2	27.3	29.4	18.9*
	150- 300	0.82	0.79	37.8	32.0	41.1	16.4
	300- 600	0.62	0.72	40.8	52.6	41.6	45.7
	600- 900	0.50	0.43	33.5	37.4	26.6	24.7
	900-1200	0.36	0.29	23.2	28.5	12.9	32.0
3-yr winter wheat	0- 75	1.32	1.28	37.9	33.6	34.7	16.5**
	75- 150	0.94	1.04	35.3	28.8	42.6	29.0
	150- 300	0.89	0.76	23.5	23.9	16.5	15.9
	300- 600	0.62	0.65	32.1	29.3	24.4	32.7
	600- 900	0.40	0.41	43.4	40.9	26.7	34.4
	900-1200	0.34	0.24	25.5	31.1	23.6	25.9
3-yr barley	0- 75	1.24	1.22	15.6	16.9	26.7	33.1*
	75- 150	0.97	0.94	17.5	18.8	21.9	14.8*
	150- 300	0.79	0.83	25.0	24.2	26.1	9.0
	300- 600	0.57	0.64	41.1	27.7	28.3	33.2
	600- 900	0.38	0.41	38.0	24.1	23.7	30.2
	900-1200	0.27	0.37	29.2	31.2	14.0	17.5

*Tillage systems significantly different (P = 0.05).

Table 3.7. Soil inorganic N in the spring and fall at Lethbridge and Vauxhall for fallow in 1984

Soil depth (mm)	Inorganic N ($\mu g\ g^{-1}$)							
	Lethbridge				Vauxhall			
	Spring		Fall		Spring		Fall	
	CT	NT	CT	NT	CT	NT	CT	NT
0- 75	12.5	9.6	22.0*	16.3	14.7	14.3	17.8	19.1
75- 150	12.1	9.8	18.2*	13.6	15.8	15.2	14.6	15.8
150- 300	4.8	4.5	10.8	9.7	22.7	22.2	20.2	14.7
300- 600	2.3	2.9	2.5	3.5	44.2*	24.5	47.3*	23.7
600- 900	2.8	2.9	2.6	2.8	50.6*	31.5	41.6*	32.5
900-1200	4.2	4.1	5.4	4.1	29.5	29.6	19.4	23.7

*Tillage system significantly different ($P = 0.05$).

3.3.5 Seed Moisture and Plant Emergence

With abundant seedbed moisture at Lethbridge in 1983 good seed moisture was (Table 3.8) present 48 hr after seeding (>820 g kg^{-1}) and good emergence (>30 m^{-1}) occurred in both tillage treatments. In 1984, seed moisture at this site was much less (<500 g kg^{-1}) for both winter wheat and the spring crops. In this situation of little seed moisture and dry seedbed, emergence and seed moisture were generally greater in the NT treatments.

Table 3.8. Seed moisture[†] and plant stand[‡] at Lethbridge and Vauxhall for CT and NT in 1983 and 1984

Site	Measurement	3-yr winter wheat		3-yr barley		Continuous wheat	
		CT	NT	CT	NT	CT	NT
Lethbridge 1983	Seed moisture	ND[§]	ND	946	911	822	876
	Stand	ND	ND	31.4	29.4	30.4	32.3
Lethbridge 1984	Seed moisture	427	476[*]	453	485	436	466[*]
	Stand	14.3	21.4[*]	18.6	21.0	11.6	24.5[*]
Vauxhall 1983	Seed moisture	ND	ND	545	395[*]	ND	ND
	Stand	ND	ND	11.6	7.4[*]	ND	ND
Vauxhall 1984	Seed moisture	427	451	540	449[*]	538 161	455[*] 241[¶]
	Stand	13.5	31.2[*]	8.7	15.8[*]	12.1	20.7[*]

[†] Seed moisture 48 hr after seeding g H_2O kg^{-1} based on dry weight of seed.

[‡] Plant number m^{-1} taken 2 wks after seeding.

[§] Not determined.

[*] Tillage systems significantly different (P = 0.05).

[¶] Continuous winter wheat, reseeded to spring wheat.

At Vauxhall, dry soil conditions in the spring of 1983 and for the fall and spring of 1984 produced meager seed moisture at 48 hr (<550 g kg^{-1}). In 1983 volunteer wheat in the NT barley treatment reduced soil moisture and restricted emergence to 7.4 m^{-1}. For the spring crops in 1984, even with less seed moisture in NT compared to CT, emergence was still greater for the NT treatment, 8.7 vs. 15.8 m^{-1} and 12.1 vs. 20.7 m^{-1} for barley and continuous spring wheat, respectively. For continuous winter wheat in 1984 the seed moisture was very meager for both tillage treatments, 161 and 241 for the CT and NT, respectively. Since plant emergence and winter survival were poor for the CT treatment, both tillage treatments were re-seeded to spring wheat.

3.3.6 Plant Yield and Chemical Composition

Plant yields taken at the first visible node stage (Tables 3.9 and 3.10), generally reflected the same differences between tillage treatments as the final harvest yield at both sites. At Lethbridge, the NT treatments were superior in yield to CT treatments for all three crops in 1984 with no yield differences in 1983. At Vauxhall, harvest yield was 2869 kg ha^{-1} in the NT compared to 2360 kg ha^{-1} in the CT treatment for winter wheat in 1983. The NT treatment yield was 1700 kg ha^{-1} for barley in 1983 and reflected the poor emergence and soil moisture at seeding for the crop. Winter wheat (3-yr rotation) and barley yields were not affected by tillage treatment in 1984.

Table 3.9. Yield and chemical composition of plant samples for CT and NT at the Lethbridge site in 1983 and 1984

			Mid-season plant sampling					
Crop	Till	Year	P	K	N	N yield	Yield	Grain harvest yield
			$g\ kg^{-1}$[†]			$kg\ ha^{-1}$		
3-yr winter wheat	CT	1983	2.53	29.0	21.2	36.5[*]	1722	2282
	NT		2.70	29.2	21.2	44.2	2083	2655
	CT	1984	1.52	19.2	18.7	36.5[*]	1952[*]	1601[*]
	NT		1.56	18.7	18.3	49.0	2676	2438
3-yr barley	CT	1983	2.78[*]	30.4[*]	23.8[*]	23.7	997	1320
	NT		3.34	32.4	26.6	22.1	830	1512
	CT	1984	2.90	29.4	25.2	5.1	204[*]	138[*]
	NT		2.90	28.2	22.9	6.4	253	293
Continuous spring wheat	CT	1983	2.46[*]	21.8[*]	18.4[*]	19.6	1063	734
	NT		2.83	23.9	21.6	16.7	771	530
	CT	1984					ND[‡]	115[*]
	NT						ND	341

[†] Dry weight.

[*] Tillage systems significantly different (P = 0.05).

[‡] Not determined.

Table 3.10. Yield and chemical composition of plant samples for CT and NT at the Vauxhall site in 1983 and 1984

			Mid-season plant sampling					
Crop	Till	Year	P	K	N	N yield	Yield	Grain harvest yield
			$g\ kg^{-1}$†			$kg\ ha^{-1}$		
3-yr winter wheat	CT	1983	3.11	41.8	41.7*	42.4*	1017	2360*
	NT		3.17	41.8	42.7	52.5	1230	2869
	CT	1984	1.84	31.6*	26.9*	38.9	1446	1578
	NT		1.90	34.6	30.1	44.2	1463	1728
3-yr barley	CT	1983	2.73*	34.5*	30.1*	98.2*	3264*	2863*
	NT		3.26	40.6	34.9	32.6	935	1700
	CT	1984	2.31	22.8	24.6	24.1	981	434
	NT		2.29	21.0	22.7	28.6	1258	574
Continuous wheat	CT	1983	2.97	39.9	38.7*	34.9	902	1258*
	NT		3.10	39.7	40.9	32.9	804	1631
	CT	1984					ND‡	118*
	NT						ND	363

† Dry weight.

* Tillage systems significantly different (P = 0.05).

‡ Not determined.

Table 3.11. Linear correlation coefficients (r) for soil and plant properties with crop[†] grain yield in 1983 and 1984

Location	Year	Crop	Seed moisture	Plant count	Total[‡] soil water	Surface[‡] soil water	In-[‡] organic N	Soil[§] temperature
			r					
Lethbridge	1983	WW			.33	.44	.52	.36$_{**}$
		B	.01	-.12	.40$_{*}$	-.04	-.24	-.87
		SW	-.27	-.11	-.66	.49	-.16	.20
	1984	WW	.65$^{*}_{*}$	.47	.73**	.23	.35	-.06$_{**}$
		B	.70	.32$_{*}$	.37	-.12	-.34$_{**}$	-.80
		SW	.49	.56	.13	.46	.62	-.60
Vauxhall	1983	WW			-.48	.11	-.33$_{**}$	
		B	.65**	.64**	.10	.09	.68	
		SW			-.20	-.29	.20	
	1984	WW	.29	.40$_{**}$	-.09	.06$_{*}$	.08	
		B	-.15$_{*}$	.71$_{**}$	-.48	-.55	-.07	
		SW	-.84	.68	-.17	.22	-.13	

[†] Winter wheat (WW), barley (B), spring wheat (SW).

[‡] Measured prior to seeding.

[§] Mean May temperature at 20-mm depth at 830 hr.

[*] Indicates significance at P = 0.10.

[**] Indicates significance at P = 0.01.

Nitrogen content of winter wheat plants did not differ between tillage treatment at Lethbridge for either 1983 or 1984. However, at Vauxhall, nitrogen content of the NT winter wheat crop was 40.9 g kg^{-1} compared to 38.7 g kg^{-1} for CT. NT barley and NT continuous wheat had a greater N concentration than respective CT treatments at both sites in 1983 but in 1984 there was no tillage treatment effect. Concentrations of P and K generally followed the same trend as N in all crops. Nutrient concentrations for crops were generally larger at the Lethbridge than the Vauxhall site.

3.3.7 Correlation Data

At the Lethbridge site in 1984, grain yield was positively correlated with spring seed moisture or plant count (Table 3.11). For barley, soil temperature was inversely correlated with grain yield in both years ($r > -.80$). The correlations of grain yield with total soil water varied from a large positive correlation ($r = .73$) for winter wheat in 1984 to a large negative correlation ($r = -.66$) for spring wheat in 1983. The negative correlation ($r = -.66$) with total soil water and spring wheat yield in 1983 at Lethbridge could have been caused by a phytotoxic effect from crop residue combined with high levels of soil moisture at seeding. The positive correlations with inorganic N and spring wheat yield ($r = .62$) at Lethbridge in 1984 and barley yield ($r = .68$) at Vauxhall in 1983 does not mean that inorganic N was deficient, for there was no yield response to fertilizer N for either tillage system (Chapter 2; Tables 2.4, 2.5).

At Vauxhall, there was a strong relationship ($r > .70$) between plant counts and grain yield for both spring crops in 1984. There was a negative or very poor correlation of seed moisture with grain yield in 1984. In 1983, grain yield was correlated with seed moisture (r = .65) and plant counts (r = .64) for barley. At Vauxhall, total soil water generally gave negative values when correlated with grain yields.

3.4 DISCUSSION

Lower soil temperatures (Table 3.1) of 13.9°C for NT compared to 14.7°C for CT barley early in the growing season were attributed to larger amounts of crop residue (Appendix 6.9). Conversely, greater soil temperatures for NT compared to CT winter wheat were caused by less soil moisture due to a better NT wheat crop. Less soil moisture decreases the heat capacity of the soil and increases the rate at which it will warm (Hay et al., 1978). Soil temperature does not appear to affect final crop yield. Tillage effects on soil temperature in the spring were quite small (<1.5°C). The negative correlation of soil temperature and final crop yield (Table 3.11) could be related to the corresponding greater soil moisture content with the decreased soil temperatures.

In the spring, inorganic N (Tables 3.5 and 3.6) was less in the top soil layer (0-75 mm) for NT crops at Lethbridge but not at Vauxhall. The large amount of inorganic N at lower soil depths (> 300 mm) for both tillage systems at Vauxhall was probably caused by mineralization of native soil organic matter and subsequent NO_3-N leaching since this land was newly broken only three years before the experiment was initiated. Some in situ mineralization may also have occurred with improved moisture and temperature regimes (Parton et al., 1983). Immobilization of N in the NT topsoil layer at Lethbridge could be due to a buildup of a mulch layer as the Lethbridge rotation was established much earlier than the Vauxhall rotation. Later in the crop season an even greater amount of inorganic N in the CT than the NT treatments compared to the spring indicated a faster rate of soil N mineralization. Poor correlation between spring soil inorganic N levels and final yields suggest that decreased crop yields under CT compared to NT were not caused by a reduced N supply. This is consistent with abundant mineral N observed throughout the study at both sites. Tillage effects on fertilizer N immobilization influenced grain N concentration even when adequate mineral N was available (Chapter 2).

Total soil water (0-1200 mm) (Table 3.2) was greater (20-30 mm) for NT than CT treatments at Lethbridge in the spring. The relative gain in soil water by the NT over the CT treatments occurred from fall to spring (Table 3.3) where better insulation by the NT surface residue layer probably prevented desiccation by dry, strong chinook winds which are prevalent during the winter months.

Similar amounts of total soil water were conserved in tillage treatments at Vauxhall (Table 3.4). Crop residue differences for tillage treatments at Vauxhall were smaller than at Lethbridge (Appendix 6.9) so the effect of crop residue on soil water conservation would have been less at the Vauxhall site. The soil at Vauxhall consisted of soil horizons of clay loam texture which may have allowed rapid capillary moisture flow to the soil surface. If an Ap horizon has an inadequate surface mulch and has good capillary continuity with lower horizons, moisture losses can be more severe than in Ap horizons with a loose tilled layer which restricts evaporation (Hammel et al., 1981; Benoit and Kirkham, 1963). The Lethbridge soil consists of a surface loam (49% sand) overlying a deeper clay loam (33% sand - Appendix 6.5). This degree of soil layering may have been sufficient to restrict capillary water movement to the soil surface. Since tillage effects on water conservation for a soil can depend upon its textural layering characteristics and also the amount of surface crop residue, more information is required on how these characteristics affect soil moisture conservation in different soils and cropping systems. The most efficient soil water conservation practice for some soils may require tillage at certain times to prevent soil water loss.

Total soil water was generally not correlated with final crop yield (Table 3.11). In 1983, a growing season with above average rainfall, total soil water for spring wheat was negatively correlated (r = -.66) with final crop yield. There may have been some degree of phytotoxicity associated with the NT treatment because of the abundant early spring moisture. In 1984, total soil water for winter wheat was positively correlated (r = .73) with final crop yield. The greater soil water conserved in the NT than the CT treatments was probably well utilized later in the growing season as the growing season in 1984 received limited rainfall and a good winter wheat crop created a large demand for water. In very dry years with limited crop growth the additional soil water conserved in the NT compared to the CT treatment may not be utilized by the current crop but would be available for crop use in the subsequent year.

Soil water (0-75 mm) (Figs. 3.1 and 3.2) was as great or greater for NT crops in the spring and fall. Soil water measured prior to seeding (0-75 mm) was not correlated with grain yield at either site. Seed moisture content and plant emergence measurements (Table 3.8) were considered better indirect indicators of the seedbed moisture status during the critical early growth period than direct soil water measurements taken before seedbed preparation. Generally greater seed moisture under NT than CT was expressed by improved plant emergence at Lethbridge. At Vauxhall, less seed moisture for NT spring crops produced better plant stands. Less seed moisture could be due to slower inbibition because of depressed spring soil temperatures in NT treatments. This phenomena did not occur in NT treatments for winter wheat in the fall.

Another explanation for the decreased seed moisture and better plant stands for the NT compared to CT treatments is related to soil disturbance in the tillage operation. This disturbance may have allowed initial seed water uptake but prevented the placement of the seed on firm soil. Loose soil could have prevented moisture from moving easily to the seed from underlying moist soil, by disrupting capillary continuity. Moisture movement from deeper soil can be critical for good plant emergence under dry conditions (Papendick et al., 1973). Recent work by Lindwall (1983) indicated that tillage can affect aggregate size distribution of the surface soil. Research studies in Europe (Håkansson and von Polgár, 1984) have shown that aggregate size distribution of seedbed soil affects uptake of soil water by seeds.

When seed moisture was low, the greater seed moisture and plant emergence in the NT treatment was reflected in larger yields. Good early growth appeared to have a direct effect on final yield. This good early growth was especially critical for winter wheat because it ensured winter survival. Previous work showed that early drought stress did not affect final yield if the stress period was followed by adequate moisture (Denmead and Shaw, 1960). The conditions in this study differed in that the stress period was generally followed by more moisture stress so there was less opportunity for the stressed CT crop to reach the same yield as the NT treatment. Long-term winter wheat rotations indicated that NT crops were often superior to CT crops when precipitation was lacking during the early part of the growing season (Carefoot and Lindwall, 1982). Noori et al. (1985) reported better stands and large yield increases by injecting small amounts of water at planting for winter wheat. The amount of water injection needed for a yield response was very critical, depending upon the dryness of the soil. Since this yield advantage for NT occurred at both sites, Vauxhall and Lethbridge, it appeared to be related more to the greater moisture in the top soil layer (0-75 mm) of the NT treatment rather than to total soil moisture conserved in the soil profile. This study shows that tillage effects on seed moisture uptake can be a critical factor for this semi-arid region.

Grain yield was correlated with plant count or seed moisture (Table 3.11) when small amounts of seed moisture and small plant counts indicated poor soil moisture conditions during seeding and the early crop growth period. The negative correlation between seed moisture and grain yield for the spring seeded crops at Vauxhall in 1984 was probably related to initial slower moisture uptake by the seeds in the NT treatment. A subsequent higher rate of plant emergence in the NT treatments resulted in a strong correlation between plant counts and grain yield.

Mid-season yield samples (Tables 3.9 and 3.10) generally reflected the same differences between tillage treatments as the harvest yields, which indicates that final yields were related to crop growth differences that occurred early in the growing season. The importance of seedbed moisture on final yield was demonstrated by the 1983 barley crop at Vauxhall. Unchecked volunteer wheat depleted spring soil moisture in the NT barley treatment which was reflected in less seed moisture (395 g kg^{-1}) and decreased plant stands (7.4 m^{-1}) for the NT compared to the CT treatment. The NT barley yield of 1700 kg ha^{-1} versus 2863 kg ha^{-1} for CT was the only situation where CT crop yield was superior to the NT treatment.

This study indicates that in semi-arid areas both producers and researchers should be more concerned about the effect of tillage on seedbed moisture early in the growing season. Conserving soil moisture at seeding should be a major goal for growers. If possible, tillage should be avoided and fertilizer placements such as broadcast, fall banding, or point injection should be used to minimize soil disturbance at seeding time.

Although the crop rotations in this study were relatively short-term (<11 yr), there were already indications of changes in total N and organic matter.

An increase in total N occurred in the top soil layer (0-75 mm) (Table 3.5) of the continuous wheat rotation (1.79 g kg^{-1}) compared to the 3-year rotation (1.70 g kg^{-1}) at Lethbridge. Rotations which include fallow generally have less organic matter and total N than continuous cropping rotations (Pittman, 1977). Organic matter content in the soil has been related to the long-term amount of crop residue addition (McGill et al., 1986; Biederbeck et al., 1984). Organic matter content (0-75 mm) was greater in the NT than the CT soil (26.0 g kg^{-1} vs. 24.3 g kg^{-1}) in the continuous wheat rotation. Long-term average yields and thus total crop residue input were 13.4 and 8.5% higher for the NT than the CT treatment in the continuous and 3-year rotation, respectively. This indicates that tillage treatment in the continuous rotation could have some impact on soil organic matter levels due to variation in crop residue addition. It is also conceivable that fallow in the 3-year rotation, with accelerated biomass turnover, would mask the effect of small differences in crop residue addition on soil organic matter level. Consequently, the 3-year rotation would take longer to develop soil organic matter differences between tillage systems.

Under conditions of low growing season precipitation, the tendency of greater inorganic N under CT than NT (Tables 3.5 and 3.6) creates the potential for larger N losses through subsequent leaching. House et al. (1984) reported that NT systems recycle N more slowly but also more efficiently. Mineral N leaching could diminish organic N content in the CT treatment but due to consecutive dry years in this study, mineral N was conserved until the next crop season to be utilized by microorganisms or taken up by the crop.

Long-term soil quality as measured by total soil organic matter and N appears to be favored more by the NT than the CT treatment in this study due to greater annual crop residue additions and the potential for more efficient N cycling.

3.5 CONCLUSIONS

Soil temperature and inorganic N did not appear to affect final crop yield.

Long-term soil quality was favored by greater annual crop residue additions and more efficient N cycling in NT compared to CT.

Greater amounts of soil water were conserved by NT compared to CT plots on a Lethbridge loam soil but not on a Chin clay loam. The difference in soil moisture conservation between soil types indicates that knowledge of soil characteristics such as textural layering and mulch layer thickness are necessary to assess the suitability of a soil type for NT farming.

Better seedbed moisture for NT compared to CT treatments at both sites was reflected by increased seed moisture content and/or better plant emergence. The correlation of good spring seedbed moisture with final crop yield in this semi-arid area suggests that conserving soil moisture at seeding should be a main objective for growers. These findings suggest that seedbed preparation tillage should be avoided if possible and fertilizer placements used that minimize soil disturbance.

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4. BIOMASS GROWTH AND MICROBIAL N IMMOBILIZATION WITH BROADCAST ^{15}N AMMONIUM NITRATE IN A GRAIN CROP ROTATION UNDER TWO TILLAGE SYSTEMS

4.1 INTRODUCTION

Soil biomass size is related to specific soil factors. Campbell and Biederbeck (1976) showed that microbial biomass was directly proportional to soil moisture content and diminished with decreasing temperatures except where lower temperatures coincide with higher moisture. Large increases in bacterial numbers have been observed in the fall after precipitation and the addition of fresh crop residues (Campbell and Biederbeck, 1982). After 50 years of cropping in two rotations, soil moisture, soil moisture change, and temperature played the major roles in short-term biomass growth while tillage and residue addition played only a minor role (McGill et al., 1986). Bottner (1985) found that soil drying killed one-quarter to one-third of the biomass but the biomass returned to its former size after re-moistening. Doran (1980) reported that crop residue additions increased soil water content which subsequently caused increases in microbial populations.

Biomass size and activity is highly correlated with soil organic matter. Soil organic matter level was increased with N fertilizer, straw incorporation, and manure addition (Schnurer et al., 1985). Soil biomass increased during the growth of a wheat crop and was greater under NT due to a greater density of roots (Lynch and Panting, 1980). Lynch and Panting (1982) found that application of N fertilizer increased the soil biomass in a direct-drill but not a plow treatment. Ross et al. (1984), in a New Zealand study, showed that soil biomass size was related to the decomposition of roots rather than the production of roots. The greater microbial biomass in the surface soil for NT relative to CT in long-term studies has been attributed to increased amounts of labile carbon and nitrogen (Carter and Rennie, 1982).

Biomass immobilization of fertilizer N into the more stable organic N forms by the soil biomass can be rapid under favorable conditions (Aulakh and Rennie, 1984; Feigenbaum et al., 1984; Olson, 1982). In contrast, if dry conditions limit crop uptake, immobilization, and denitrification of fertilizer N, the residual inorganic N can be well utilized by the subsequent crop (Olson and Swallow, 1984).

Tillage can affect fertilizer N immobilization but the results are variable (Kitur et al., 1984; Rice and Smith, 1984; Carter and Rennie, 1984b). Immobilization of added ^{15}N fertilizer was higher under CT than NT when extra straw was incorporated (Aulakh et al., 1984).

Recent studies have shown that immobilized fertilizer N can be remineralized in the same growing season. Bwardwaj and Novak (1978), from an incubation study, predicted that if residues are allowed to decompose under optimum temperature and moisture conditions for two months before seeding, appreciable amounts of previously immobilized N would be mineralized to the growing crop.

Moisture and temperature fluctuations at the soil surface produce conditions that favor rapid mineralization of immobilized fertilizer N

(Carter and Rennie, 1984a). The N content of the NH_4-N flush associated with rhizosphere development and decrease of fertilizer N in biomass N had a short half-life of about 20 days. By Feekes Stage 5 of spring wheat on a Lethbridge loam, about 37% of the added fertilizer N was immobilized and most of this remineralized by harvest in CT and NT. Carter and Rennie (1984b) found that fertilizer N uptake by biomass and subsequent mineralization was not affected by tillage treatment.

House et al. (1984) reported that NT systems recycle N more slowly but also more efficiently than CT.

The flush of CO_2-C from soil after chloroform fumigation (Fc) provides an estimation of biomass C in soil (Jenkinson and Powlson, 1976). Likewise, the flush of N after fumigation (Fn) provides an estimate of biomass N. Elliot et al. (1984) found that a decrease of the Fc/Fn from 5.6 to 3.1 in response to increasing soil moisture was due to a shift from fungal to bacterial microflora. Biederbeck et al. (1984) reported that the Fc/Fn ratio was highest in rotations with greater cropping intensity and without N fertilizer. This was attributed to a shift toward a more fungi-dominated system or a biomass with a larger dormant fraction having a high C/N ratio. No-till management increased the importance of fungi relative to bacteria as primary decomposers. Fungi-dominated systems were most pronounced under arid or semi-arid conditions and were associated with slower decomposition of organic matter and less nutrient mobility (Hendrix et al., 1986).

Long-term cereal rotations at the Lethbridge Research Station have shown that grain yields on NT were often superior to CT, particularly when soil moisture was limiting at critical early growth stages (Carefoot and Lindwall, 1982). Carter and Rennie (1982) found greater potential microbial biomass and mineralizable C and N potentials in the NT surface soil compared to the CT surface soil (0-20 mm) but the reverse situation occurred in the 20-40 mm soil layer. The microbial biomass N and the amount of fertilizer N immobilized in the biomass were related to the amount of crop residue and time of incorporation (Carter and Rennie, 1984b). By harvest, no differences in N transformations between tillage treatments remained (Carter and Rennie, 1984b). Low growing season precipitation and greater crop residue levels could conceivably accentuate these differences between tillage practices.

Crop yield and crop N concentration increases with added fertilizer N occurred most often in NT spring seeded crops, and appeared to be caused by substantial fertilizer N immobilization (Chapter 2). Fertilizer N immobilization was affected by crops, weather, and tillage. The amount of fertilizer N immobilization appeared to depend on the amount of high C/N substrate available when soil conditions promoted microbial growth.

Based on the results from Chapter 2 and the literature to date, it is hypothesized that tillage induced changes in microbial growth affect the soil N cycle and subsequently crop growth. It is also hypothesized that critical edaphic factors that affect fertilizer N immobilization in the biomass are soil moisture and amount of high C/N substrate.

The above hypotheses were tested by measuring biomass, soil mineral N, labelled fertilizer N in the soil organic fraction and in the biomass, and several edaphic parameters over two growing seasons for two crop rotations.

4.2 MATERIALS AND METHODS

The main field experiments were established in 1976 on a Lethbridge loam at Lethbridge, Alberta. The complete experimental design amd pertinent soil and precipitation data were provided elsewhere (Chapter 2). Two grain rotations were selected for use in this study: 1) Winter wheat-barley-fallow (W-B-F) and 2) Continuous wheat (CW). The three crops and one fallow per year each included two tillage treatments: 1) heavy-duty cultivator; 2) no-till. A split-plot design with five blocks was used, the three crops and fallow were main plots and the two tillage treatments were as subplots (6x40 m). In 1984 (for 3 crops) and 1985 (for 2 crops), three N rates (1x1 m) as sub-subplots were superimposed on the tillage subplots to create a split-split-plot design. This gave a total of 5x4x2=40 sub-subplots per crop. Tillage practices, herbicide applications, and seeding practices were described elsewhere (Carefoot and Lindwall, 1982).

Fertilizer was applied by dissolving ammonium nitrate in 500 ml of H_2O and spraying the solution on 1-m^2 plots at N rates equivalent to 25 and 50 kg ha^{-1} for barley and spring wheat. Similarly, N rates equivalent to 15 and 30 kg ha^{-1} were used for winter wheat. The fertilizer N contained 4.98% ^{15}N and 5.48% ^{15}N (atom %) in 1984 and 1985, respectively.

4.2.1 Sampling

In July of 1984, and April, June, and August of 1985, the sub-subplots for the check and the highest N rate were sampled at depth increments of 0-75, 75-150, and 150-300 mm (Appendix 6.1). Field moist soil samples were mixed, passed through a 2-mm sieve, and stored at 5^{o}C. In 1985, the fertilizer residual N plots from 1984 were also sampled in April, June, and August.

4.2.2 Soil Analysis

Soil microbial biomass was determined by chloroform fumigation within 24 hours of sampling (Jenkinson and Powlson, 1976). Two 50-g subsamples were weighed out from each main soil sample, (control and fumigated). Each subsample was placed in a quart jar with a beaker containing 20 ml of .3 M NaOH. After incubation, the NaOH solution was removed, 2 ml of saturated $BaCl_2$ was added, and CO_2 was determined by titration with .1 M HCl. The flush of CO_2-C (Fc) was calculated as the amount of CO_2-C evolved in the 10 days after fumigation minus that produced by the unfumigated soil between 10 and 20 days. Biomass C was calculated by dividing the flush of CO_2-C by a Kc factor of 0.411 (Anderson and Domsch, 1978). Potential microbial activity was calculated as the ug of CO_2-C released from 1 mg of biomass C in the first 10-day period of the control soil incubation (Bottner, 1985).

The flush of N was calculated as the amount of inorganic N released in the 10 days after fumigation minus the inorganic N released in the control for the same period. NH_4-N and NO_3-N were measured in 2 N KCl extracts by steam distillation (Bremner, 1965). Samples containing <0.5 mg of N were spiked with 1 mg of NH_4^+-N as analytical grade $(NH_4)_2SO_4$. Soil samples were analyzed for total N using a predigestion treatment of $KMnO_4$ and reduced iron to convert NO_2^- or NO_3^- to NH_4^+ (Bremner, 1965). All distillates were evaporated at 65°C and the N^{15}/N^{14} contents were determined on a VG Micromass SIRA12 mass spectrometer.

4.2.3 Statistics

Analysis of variance was carried out based on a split-split-plot design (Reps Crops/Tillage/N). Standard errors for testing effects of the factors applied to main plots, subplots, and sub-subplots as well as their interactions were determined as described by Little and Hills (1978).

4.2.4 Calculations

Percent N derived from fertilizer (%NDFF) was calculated as follows for the total soil N (Middleboe et al., 1976):

$$\%NDFF = \frac{\text{N \% atom excess (soil)}}{\text{N \% atom excess (fertilizer N)}} \times 100$$

$$\text{Fertilizer N kg ha}^{-1} = \frac{\%NDFF}{100} \times \text{bulk density Mg m}^{-3} \times \text{area of soil}$$

$$\text{cm}^2\ \text{ha}^{-1} \times 10^{-8} \times \text{soil depth cm} \times \frac{\text{\% total N in soil}}{100}$$

$$\times \frac{1\ \text{kg}}{1000\ \text{g}}$$

Fertilizer N in the flush of N after fumigation and in the inorganic soil fraction was calculated in a similar manner:

$$\text{Fertilizer N kg ha}^{-1}\text{(inorganic N)} = \frac{\%\text{NDFF}}{100} \times \text{bulk density Mg m}^{-3} \times \text{area of soil cm}^{2}\ \text{ha}^{-1} \times 10^{-8} \times \text{soil depth cm} \times \frac{\%\ \text{inorganic N in soil}}{100} \times \frac{1\ \text{kg}}{1000\ \text{g}}$$

4.3 RESULTS

4.3.1 Biomass C

Spring soil biomass in the surface (0-75 mm) was 664 kg ha^{-1} in NT compared to 484 kg ha^{-1} in CT for winter wheat and 747 kg ha^{-1} in NT compared to 635 kg ha^{-1} in CT for barley (Table 4.1). In the residual N plots (Table 4.2) soil biomass C (0-75 mm) in spring was 759 kg ha^{-1} in CT spring wheat compared to 611 kg ha^{-1} in NT spring wheat but there was no tillage effect on plots seeded to barley.

At mid-season in 1984 (Table 4.3) soil biomass (0-75 mm) increased with fertilizer N for barley (528 to 725 kg ha^{-1}) and CT winter wheat (436 to 513 kg ha^{-1}). Soil biomass C (0-75 mm) was 404 kg ha^{-1} for NT compared to 513 kg ha^{-1} for CT winter wheat at the high N level. This effect may be attributable to less soil moisture (Chapter 2) in the NT compared to CT treatments as a result of greater moisture utilization by the greater-yielding NT crop.

Table 4.1. Soil biomass C (kg ha^{-1}) of winter wheat and barley plots under CT and NT in 1985

Crop	N applied (kg ha^{-1})	Depth (mm)	Date (month-day)					
			04-23		06-03		08-21	
			CT	NT	CT	NT	CT	NT
Winter wheat	30	0- 75	664*	484	482	533	547	647*
		75-150	370*	294	367	319	302	338
Barley	50	0- 75	747*	635	555	555	630	737*
		75-150	321	302	341	450	285	326

*Tillage systems significantly different at P = 0.05.

Table 4.2. Soil biomass C (kg ha^{-1}) of residual N plots under CT and NT in 1985

Crop	N applied (kg ha^{-1})†	Depth (mm)	Date (month-day)					
			04-18		06-13		08-21	
			CT	NT	CT	NT	CT	NT
Barley	30	0- 75	545	560	482	487	550	555
		75-150	394	372	384	321	331	290
Fallow	50	0- 75	616	572	423	521*	455	552*
		75-150	333	370	290	319	363	345
Spring wheat	50	0- 75	759*	611*	567	608*	599	640*
		75-150	404	438	304	321	321	338

†Fertilizer N added in 1984.

*Tillage systems significantly different at P = 0.05.

Table 4.3. Soil microbial biomass parameters of winter wheat and barley plots at two N levels under CT and NT on 1984-07-15

Crop	N applied (kg ha^{-1})	Depth (mm)	Biomass C (kg ha^{-1})		NH_4-N Flush (kg ha^{-1})		Fc/Fn[†]		Biomass activity[‡]	
			CT	NT	CT	NT	CT	NT	CT	NT
Winter wheat	0	0- 75	436	399	42.9	40.9	4.2	4.0	113	98
		75-150	229	287	25.0	25.9	4.0	4.8*	160*	84
	30	0- 75	513*	404	45.1*	36.3	4.7	4.6	52	88*
		75-150	238	333	24.2	27.2	4.0	5.0*	86	76
Barley	0	0- 75	499	545	46.6	42.1	4.4	5.3*	150	169
		75-150	236	277	29.6	29.3	3.3	3.9	68	65
	50	0- 75	652	798*	61.3	55.1	4.4	6.0*	155	187
		75-150	241	314	29.9	28.6	3.3	4.5*	128	66

[†] Flush of CO_2-C/flush of NH_4-N after sample fumigation.

[‡] μg of CO_2-C released by 1 mg of biomass C during a 10-day incubation.

* Tillage systems significantly different at $P = 0.05$.

In June of 1985, a dry year, there was no difference in soil biomass C between tillage treatments for barley and winter wheat at (Table 4.1). In the residual N fertilizer plots (Table 4.2) at mid-season, there was no difference in soil biomass C content between tillage treatments for barley and only small increases for NT fallow and spring wheat (Table 4.2).

After harvest, there was a reverse trend from that observed in spring. Biomass C (0-75 mm) increased for NT compared to CT from 547 to 647 kg ha^{-1} in winter wheat and 630 to 737 kg ha^{-1} in barley (Table 4.1). On the residual N spring wheat and fallow plots in the fall NT biomass was larger than CT biomass, 599 vs. 640 kg ha^{-1} and 455 vs. 552 kg ha^{-1}, respectively (Table 4.2). Biomass C at the lower soil depths was not affected by tillage and fertilizer N.

In all crops and depths, biomass C declined from spring to summer, then increased again in fall.

4.3.2 NH_4-N Flush

In the spring, Fn (0-75 mm) was greater for CT in both crops (Table 4.4) averaging 46.2 for CT and 37.2 kg ha^{-1} for NT. In the spring wheat residual N plots, Fn (0-75 mm) was 43.5 for CT and 33.5 kg ha^{-1} for NT (Table 4.5).

Table 4.4. Flush of N (kg ha^{-1}) after fumigation of soil samples from winter wheat and barley under CT and NT in 1985

			Date (month-day)					
			04-23		06-03		08-21	
Crop	N applied (kg ha^{-1})	Depth (mm)	CT	NT	CT	NT	CT	NT
Winter wheat	30	0- 75	42.6*	35.5	37.5	40.5	33.4	36.9
		75-150	21.9	21.1	22.9	22.5	13.9	17.6
Barley	50	0- 75	49.8*	38.8	38.2	37.9	38.0	37.1
		75-150	20.6	18.8	20.6	22.0	13.6	16.2

*Tillage systems significantly different at P = 0.05.

At mid-season in 1984 (Table 4.3) the Fn (0-75 mm) for CT winter wheat was 45.1 kg ha^{-1} compared to 36.3 kg ha^{-1} for NT when 30 kg ha^{-1} of N was added. In the fall of 1985, the only change in Fn related to tillage was in the fallow residual N plots (Table 4.5) where Fn in NT was 37.0 kg ha^{-1} vs. 28.5 kg ha^{-1} in CT. The similar Fn values for tillage treatments for soil at harvest contrasted with the Fc values since Fc for NT was usually larger than CT.

Table 4.5. Flush of N (kg ha^{-1}) after fumigation of soil samples from residual N plots† under CT and NT in 1985

			Date (month-day)					
	N applied	Depth	04-18		06-13		08-21	
Crop	(kg ha^{-1})	(mm)	CT	NT	CT	NT	CT	NT
Barley	30	0- 75	31.6	33.0	35.0	32.5	34.0	34.4
		75-150	17.4	18.1	20.8	19.9	14.7	14.1
Fallow	50	0- 75	34.4	32.8	27.8	36.8*	28.5	37.0*
		75-150	17.2	21.0	19.2	23.3	24.2	22.2
Spring wheat	50	0- 75	43.5*	33.5	45.4	42.9	32.0	33.6
		75-150	20.7	20.5	22.2	22.0	12.4	17.6

†Fertilizer added in 1984.

*Tillage systems significantly different at $P = 0.05$.

Fn at the lower soil layer (75-150 mm) was not affected by fertilizer N or tillage. Small Fn values (≤17.6 kg ha^{-1}) for both tillage treatments occurred in the fall for barley and spring wheat.

4.3.3 Fc/Fn Ratios

Fc/Fn ratios (ratio of C flush to N flush) were generally larger in the spring, decreased in mid-season, and increased again in the fall (Tables 4.6,4.7). Fc/Fn ratios usually increased with depth. There was very little effect of fertilizer N on Fc/Fn (Table 4.3) but at certain times of the year there were tillage effects. In the spring (0-75 mm), Fc/Fn for winter wheat plots was 5.6 for NT compared to 6.4 for CT, but in barley plots ratios were 6.1 for CT and 6.8 for NT (Table 4.6). In the fall (0-75 mm), Fc/Fn was greater for NT than CT crops.

Table 4.6. Flush of C/flush of N after sample fumigation of soil under winter wheat and barley in CT and NT in 1985

			Date (month-day)					
			04-23		06-03		08-21	
Crop	N applied (kg ha^{-1})	Depth (mm)	CT	NT	CT	NT	CT	NT
Winter wheat	30	0- 75	6.4*	5.6	5.3	5.3	6.7	7.2*
		75-150	6.9*	5.8	6.6	5.9	8.9*	7.9
Barley	50	0- 75	6.1	6.8*	6.2	6.1	6.8	8.2*
		75-150	6.5	6.6	6.9	6.6	8.6	8.3

*Tillage systems significantly different at P = 0.05.

Fc/Fn varied less with tillage in the fertilizer residual N plots than in the plots fertilized in 1985 (Table 4.7). Fc/Fn ratios were less in 1984 at mid-season than in 1985 at mid-season (Tables 4.3,4.6) for winter wheat and barley treatments.

Table 4.7. Flush of C/flush of N after fumigation of soil samples from residual N plots[†] under CT and NT in 1985

			Date (month-day)					
	N applied	Depth	04-18		06-13		08-21	
Crop	(kg ha^{-1})	(mm)	CT	NT	CT	NT	CT	NT
Barley	30	0- 75	7.1*	7.0	5.6*	6.1	6.6*	6.5
		75-150	9.5	8.3	7.6	6.6	9.3	8.4
Fallow	50	0- 75	7.4	7.2	6.3	5.8	6.6	6.1
		75-150	8.1	7.2	6.2	5.6	6.2	6.4
Spring wheat	50	0- 75	7.2	7.5	5.1	5.8	6.8*	7.1
		75-150	8.0	8.8	5.6	6.0	10.6	7.9

[†] Fertilized in 1984.

[*] Tillage systems significantly different at P = 0.05.

4.3.4 Fertilizer N in the Flush of N

At mid-season, the amount of fertilizer N in the Fn (0-75 mm) was similar for tillage treatments for the barley soil but was larger for NT than for CT under winter wheat (.72 vs. .28 kg ha^{-1}) (Fig. 4.1). From mid-season to fall (1985), fertilizer N content in the Fn (0-75 mm) increased for winter wheat soil but decreased for barley soil in both tillage systems. For the fertilizer residual N plots, the fertilizer N in the Fn decreased slightly from the mid-season 1984 winter wheat soil (Table 4.8) (0-75 mm) to the spring 1985 barley soil (Fig. 4.1) (.43 to .36 kg ha^{-1} for CT and .53 to .49 kg ha^{-1} for NT).

The fertilizer N in the Fn decreased substantially from the barley soil (Table 4.8, 84-07-15) to the fallow soil (Fig. 4.1, 85-04-18). The decrease was from 1.87 to 0.48 kg ha^{-1} in CT and from 1.68 to 0.57 kg ha^{-1} in NT. As the season progressed, fertilizer N in the Fn for barley and fallow (Fig. 4.1) decreased at mid-season but increased again in the fall. For spring wheat, the trend was different as the fertilizer N in the Fn decreased over the growing season in both tillage systems.

Table 4.8. Distribution of fertilizer N† (kg ha^{-1}) in the various soil N fractions of winter wheat and barley under CT and NT in 1984 and 1985

Crop	Depth (mm)	Inorganic		Organic‡		Total		Fn	
		CT	NT	CT	NT	CT	NT	CT	NT
Winter wheat 84-07-15	0- 75	2.41	0.13*	2.90	6.35*	5.74	7.01	0.43	0.53
	75-150	1.77	0.08*	1.53	3.16*	3.40	3.46	0.10	0.16
	150-300	0.09	0.03	1.56	1.29	1.68	1.38	0.06	0.06
Barley 84-07-15	0- 75	4.41	0.85*	2.06	10.99*	8.34	13.52*	1.87	1.68
	75-150	6.51	0.28*	2.03	1.42*	8.87	1.99	0.33	0.29
	150-300	0.85	0.17	2.35	2.79	3.36	3.23	0.16	0.27
Winter wheat 85-06-03	0- 75	6.81	9.81	6.86	3.42*	13.95	14.32	0.28	0.72*
	75-150	1.59	1.08	1.00	1.03	2.65	2.18	0.06	0.07
	150-300	0.22	0.22	2.51	2.68	2.73	2.90		
Barley 85-06-03	0- 75	11.51	9.01	9.71	11.04	22.25	21.01	1.03	0.96
	75-150	1.10	1.03	0.64	1.07	1.83	2.23	0.09	0.13
	150-300	0.26	0.21	2.51	2.14	2.77	2.35		

†Winter wheat fertilizer N = 30 kg ha^{-1} of N as NH_4NO_3;
Barley fertilizer N = 50 kg ha^{-1} of N as NH_4NO_3.

‡Organic fraction minus NH_4-N flush.

*Tillage systems significantly different at $P = 0.05$.

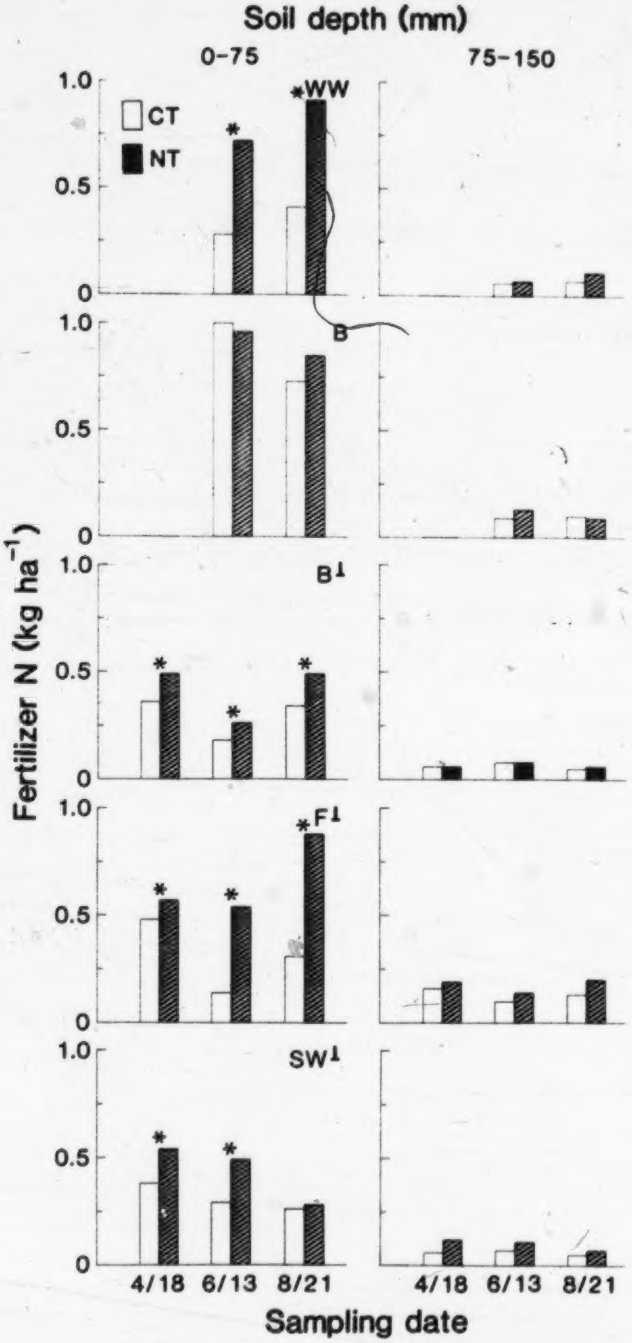

Fig. 4.1 Fertilizer N in the flush of N after fumigation of soil samples from two soil layers and three sampling dates for crops and fallow under CT and NT in 1985. (* Tillage systems significantly different at P=0.05. [1] Fertilizer residual plots were fertilized in 1984).

4.3.5 Fertilizer N in the Soil

The distribution of fertilizer N between the different soil nitrogen fractions at mid-season varied between years (Table 4.8). In 1984, a year with several heavy June showers, a greater portion of the fertilizer N in the soil was immobilized into organic forms compared to inorganic N (average of 8.67 vs. 0.49 kg ha^{-1}) in the NT treatments for both crops. In the CT treatment, a larger portion of the soil fertilizer N remained as inorganic N (average of 2.58 vs. 3.41 kg ha^{-1}).

Transformations of soil N were different in 1985, a very dry crop season. A large part (21 to 37%) of the fertilizer N remained as inorganic N in both tillage systems. For winter wheat, a greater amount of fertilizer N was converted into the organic fraction in the CT than in the NT treatment (6.86 vs. 3.42 kg ha^{-1}). This result was in contrast with the results of 1984.

The percent N derived from fertilizer (%NDFF) of the inorganic N fraction was much less in NT than CT for both crops (Fig. 4.2). The %NDFF in the inorganic N fraction was much greater in 1985 than 1984 for both tillage treatments. The %NDFF in the Fn did not appear to be related to the %NDFF of the inorganic N fraction. In both years, the %NDFF for Fn was similar for the tillage systems for barley (0-75 mm) but larger for NT than CT winter wheat. None of these differences was evident in the lower soil layers.

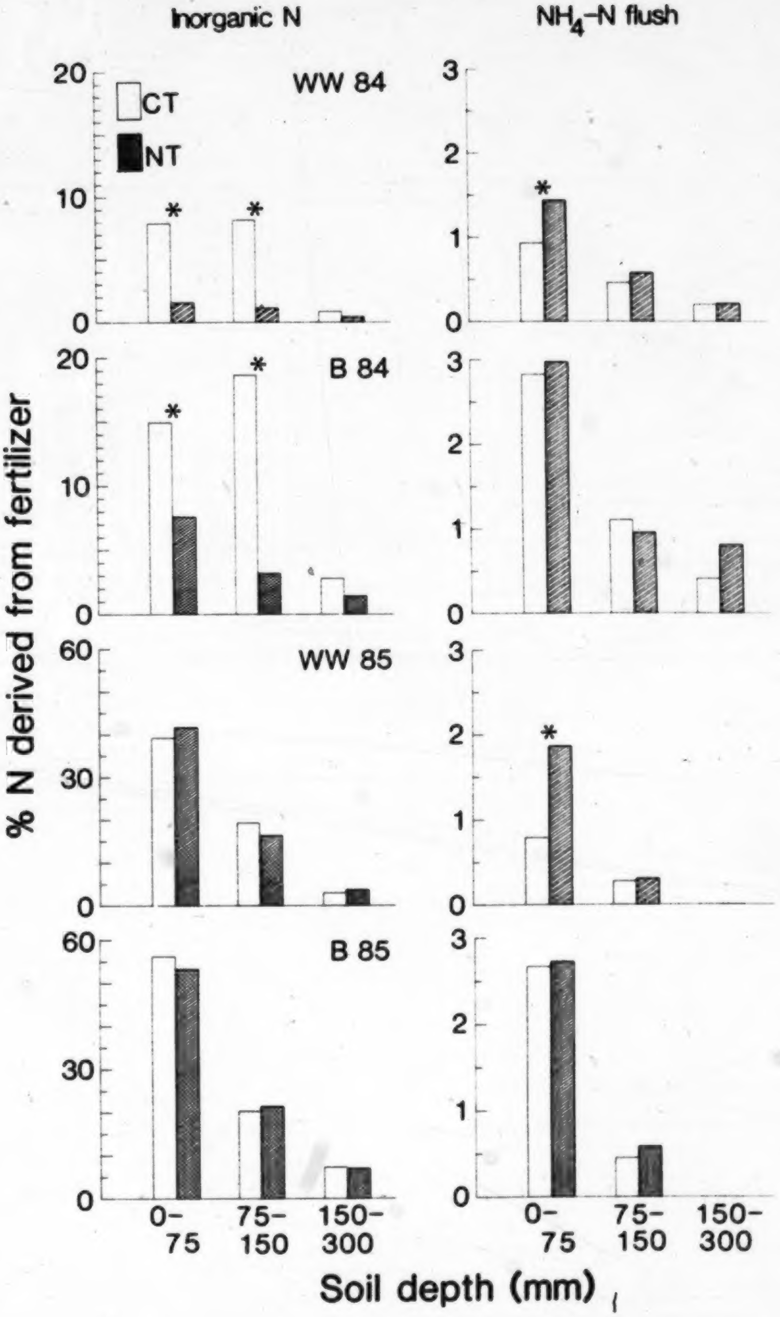

Fig. 4.2 Percent of soil inorganic N and the flush of N derived from fertilizer after fumigation of soil samples from three soil layers for winter wheat and barley plots under CT and NT in 1984 and 1985.
(* Tillage systems significantly different at P=0.05).

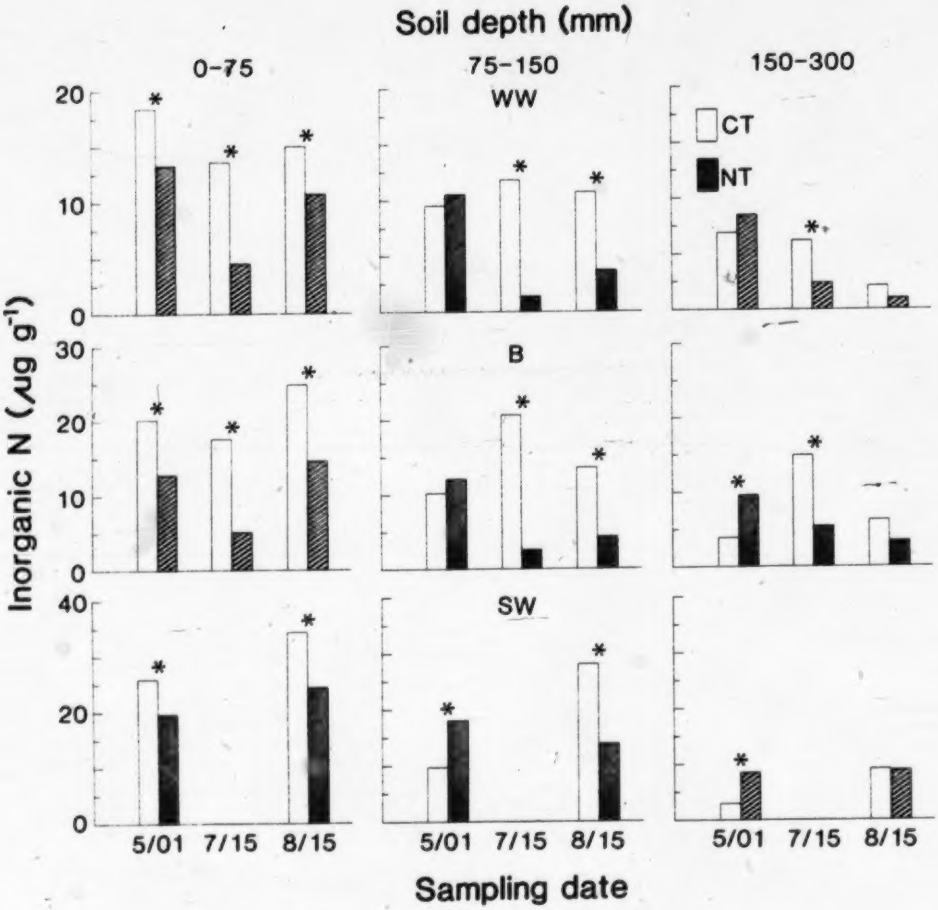

Fig. 4.3 Inorganic N for three soil layers and three sampling dates of 3 crops under CT and NT in 1984.
(* Tillage systems significantly different at $P = 0.05$).

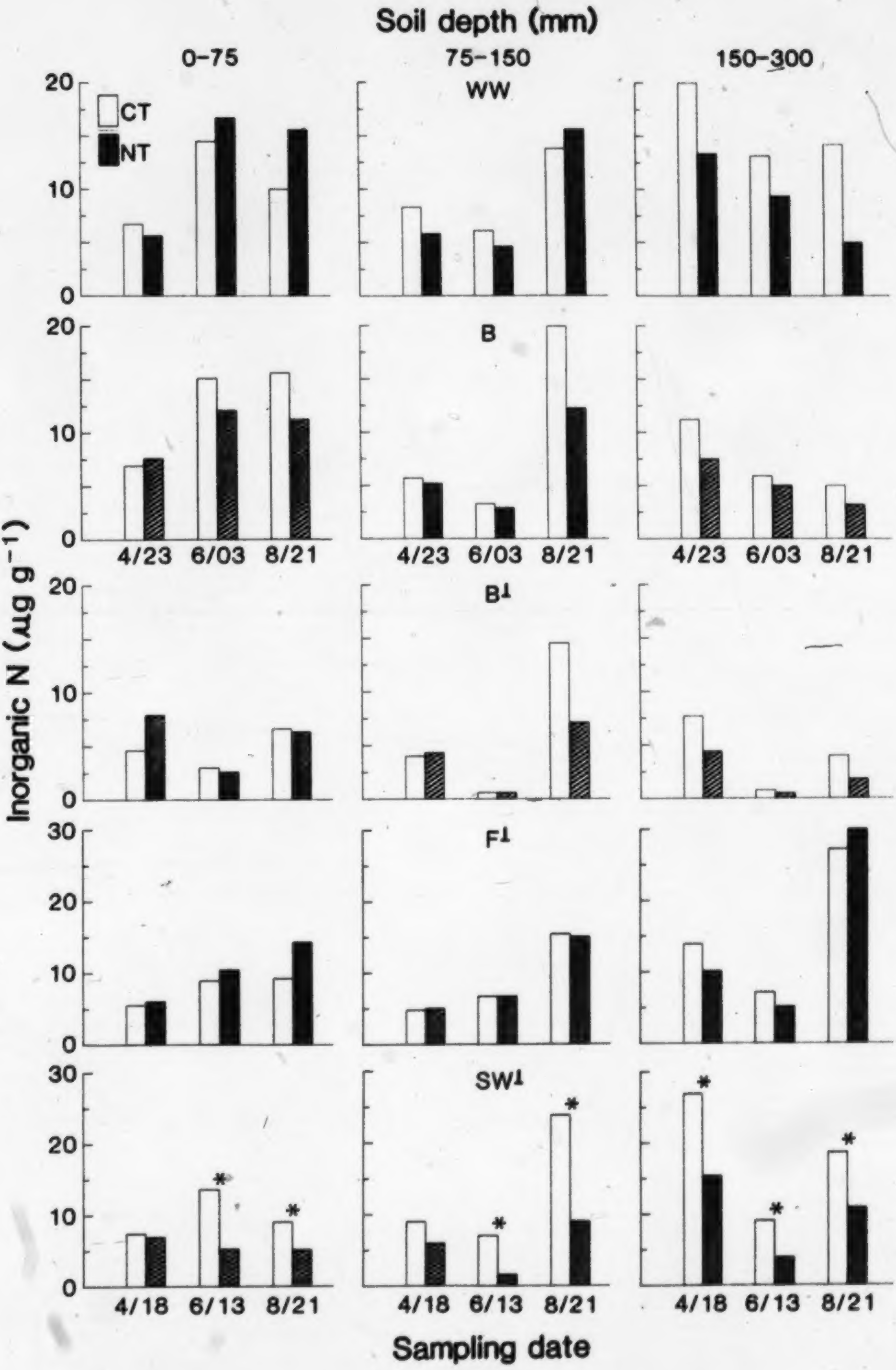

Fig. 4.4 Inorganic N from three soil layers and three sampling dates of 3 crops and fallow under CT and NT in 1985. (*Tillage systems significantly different at P=0.05. ¹Fertilizer residue plots were fertilized in 1984).

4.3.6 Soil Inorganic N

Less inorganic N in the soil in NT than CT treatments for crops by mid-season in 1984 (Fig. 4.3) was attributed to greater immobilization of fertilizer N. The situation was quite different for the dry growing season in 1985 (Fig. 4.4) when inorganic N was similar for the tillage treatments for both crops. In the fall, with better moisture conditions, inorganic N was released in both crop rotations. The inorganic N levels in the fertilizer residual N plots were similar for the tillage treatments for barley and fallow plots (Fig. 4.4). As the season progressed, greater fertilizer N immobilization in the NT than the CT spring wheat treatment resulted in less inorganic N in NT than the CT treatment.

4.3.7 Potential Microbial Activity

Soils were incubated under ideal moisture and temperature conditions so the limiting factors were substrate and the ability of the existing microbial population to respond to the incubation conditions. Thus, potential microbial activity served as an indirect measure of potential available substrate. Potential microbial activity was strongly influenced by crop, tillage, and season. In the spring, potential microbial activity (0-75 mm) (Table 4.9) was 219 μg of CO_2-C for the NT treatment compared to 114 μg of CO_2-C for the the CT treatment for winter wheat. A greater amount of potential microbial activity for NT relative to CT treatments continued through the season for winter wheat but the potential microbial activity of NT for barley remained at about the same level as in the CT treatment until harvest. Potential microbial activity in the spring in the 75-150 mm soil layer was greater for the CT than the NT treatment in the barley and winter wheat plots. Potential microbial activities were generally greater in the NT than the CT treatment for crops on residual N plots (Table 4.10). Potential microbial activities at mid-season of 1984 (Table 4.3) were lower than those in corresponding treatments at mid-season in 1985 (Table 4.9).

Table 4.9. Potential microbial activity[†] of soil samples from winter wheat and barley plots under CT and NT in 1985

			Date (month-day)					
	N applied	Depth	04-23		06-03		08-21	
Crop	(kg ha^{-1})	(mm)	CT	NT	CT	NT	CT	NT
Winter wheat	30	0- 75	114	219*	69	119*	144	259*
		75-150	154*	102	76	94	94	94
Barley	50	0- 75	264	216	239	199	205	202
		75-150	131*	79	115	97	113	128

[†] μg of CO_2-C released by 1 mg of biomass C during 10-day incubation.

*Tillage systems significantly different at $P = 0.05$.

Table 4.10. Potential microbial activity of soil samples from residual N plots[†] under CT and NT in 1985

Crop	N applied (kg ha^{-1})[†] [‡]	Depth (mm)	04-18		06-13		08-21	
			CT	NT	CT	NT	CT	NT
Barley	30	0- 75	88	133*	118	141*	179	232*
		75-150	127*	63	93	113	88	98
Fallow	50	0- 75	82	94	102	132*	90	134*
		75-150	87	87	67	81	147	165
Spring wheat	50	0- 75	79	105	87	132*	141	157
		75-150	82	108	66	62	95	118

[†] Fertilized in 1984.

[‡] µg of CO_2-C released by 1 mg of biomass C during a 10-day incubation.

*Tillage systems significantly different at $P = 0.05$.

Table 4.11. Correlation coefficients (r) of soil properties with biomass in 1985 at Lethbridge

Crop	Date	Potential microbial activity	Inorganic N	Soil temperature
Winter wheat	04-23	.494	-.120	-.637
	06-03	.919*	.552	.582
	08-21	.890*	.957*	-.410
Barley	04-23	.348	.092	.795*
	06-03	.937*	-.208	-.168
	08-21	.550	-.329	-.486

*Indicates significance at $P = 0.01$.

4.3.8 Correlation of Biomass and Soil Properties

There was generally a good correlation between potential microbial activity and soil biomass at mid-season and in the fall (Table 4.11). Soil temperature was positively correlated ($r = .795$) with soil biomass in the spring for barley. There was a very poor correlation between inorganic N and biomass except for the winter wheat treatment in the fall ($r = .957$).

4.4 DISCUSSION

Growing season precipitation ~~for~~ 1984 and 1985 was 94.1 and 55.4 mm, respectively, compared to the long-term average of 94.1 mm. The amount and timing of growing season precipitation (Chapter 2, Fig. 2.1) had a major effect on biomass growth and the soil nitrogen cycle.

In 1985, biomass differences between tillage systems varied over the season. The major control on biomass growth for both tillage systems was soil moisture (correlation coefficient = 0.86, $P < 0.01$). Biomass was larger in the spring and fall when soil moisture was adequate. At certain times of the growing season, tillage induced differences in soil parameters affected biomass size. Greater biomass C for CT than NT barley (747 vs. 635 kg ha^{-1}) prior to tillage in the spring was associated with higher soil temperatures. Soil temperatures (Chapter 3, Table 3.1) measured in this study and those observed by others (Carter and Rennie, 1985) were often less under NT early in the growing season because of more crop residue and/or greater soil moisture. Greater amounts of biomass C for CT winter wheat compared to the NT treatment (664 vs. 484 kg ha^{-1}) probably reflects the crop residue incorporated the previous fall. Tillage would incorporate the crop residue in the soil in a more favorable moisture environment. Moisture (0-75 mm) was depleted more in the NT than the CT soil in the spring due to a much more advanced crop. Desiccation of surface crop residue in the NT treatment by strong chinook winds would hinder biomass growth.

Biological activity can be affected by crop growth. Crop roots can increase biomass by supplying rhizosphere organisms with C substrate, but they can also affect biomass through their effect on soil properties such as temperature and moisture (Alexander, 1977). Tillage effects on biomass were related to root density differences (Lynch and Panting, 1980). In the current study, crop growth was more advanced for the NT than the CT treatment for winter wheat in the spring. Greater biomass in the CT than the NT treatment suggests that increased moisture removal by the more advanced NT crop had a deleterious effect on biomass rather than an enhancement due to greater root growth. Later in the summer, lack of moisture caused by scant precipitation and crop removal of soil moisture, was the dominant effect on biomass. In the fall, after harvest, the main effect on biomass appeared to be greater soil moisture in NT than CT treatments.

Lack of difference in amounts of biomass between tillage treatments for barley plots on the residual N plots (Table 4.2) could have been caused by small crop residue amounts due to removal at the fall harvest. Greater biomass C in the NT than CT fallow treatment (552 vs. 455 kg ha^{-1}) was likely a result of more soil moisture in the NT than the CT treatment. Surface soil in the CT treatment would tend to dry out with repeated tillage operations. The considerable amount of organic C (Chapter 3, Table 3.5) in the surface soil layer (0-75 mm) of the continuous NT wheat rotation and its effect on spring soil temperature and seasonal soil moisture content was likely responsible for the same tillage effects on biomass for the residual N plots as the current 1985 crops where the previous crop residue was retained on the plots.

Variations in growth patterns of biomass between tillage systems in this study have important implications for crop growth and crop response to fertilizer N. Early season biomass in the CT treatments with an accompanying greater Fn suggests that biomass demand for N will occur before the period of maximum uptake of N by the crop. In addition, N that was immobilized early in the season may be released later in the growing season to be utilized by the growing crop. In contrast, the growth of biomass later in the growing season in the NT treatments will probably compete with the growing crop for N which will not be released in time for crop utilization. Competition for N at a critical time could produce decreased crop yields and/or reduced grain N content for the NT system.

Linear correlations between biomass and various soil parameters were carried out for specific dates (Table 4.11) so the main data comparison was across tillage systems rather than with time. Correlation between biomass C and potential microbial activity at mid-season indicated a link between crop residue substrate and biomass size. The correlation late into the season suggested that the fresh crop residue substrate was not being used up, so the greater biomass size was probably the result of soil parameters such as soil temperature or soil moisture related to crop residue cover. McGill et al. (1986) showed that biomass was correlated more with soil moisture and temperature than with tillage and crop residue addition. Biomass C and potential microbial activity was not correlated in the spring. In the spring, biomass size was greater in the CT than the NT treatments. Early in the season potential microbial activity was not affected by tillage in barley plots and was greater in the NT than the CT treatment for winter wheat.

A positive correlation between biomass and soil temperature for the barley plot (r = .795) indicated that higher temperatures for the CT than the NT treatment in the spring encouraged better microbial growth. The negative correlations between biomass and soil temperature for the winter wheat treatment in the spring and fall (r = -.637 and r = -.410, respectively), and for the barley treatment in the fall (r = -.486), was probably caused by soil moisture differences. Greater soil moisture (Chapter 2, Table 2.2) and lower soil temperature (Chapter 3, Table 3.1) were reported for the CT winter wheat treatment in the spring and in the NT crop treatments in the fall.

Tillage-induced differences in soil moisture, soil temperature, and crop residue incorporation appeared to be responsible for the difference in biomass between tillage systems observed in this study. Identification of soil parameters governing biomass growth may facilitate adoption of management techniques, such as timing of crop residue incorporation, which minimize biomass N immobilization when biomass is competing with crops for N and to maximize biomass N uptake outside of this competitive period to conserve soil N.

The amount of incorporation of fertilizer N into the soil organic phase (Table 4.8) by mid-season was affected by crop, tillage, and year. In 1984, fertilizer N immobilization was much greater for NT than CT in both crops. In 1985, fertilizer N immobilization was 6.86 kg ha^{-1} for CT compared to 3.42 kg ha^{-1} for NT winter wheat plots, and there was no difference between barley tillage treatments. Generally, only a small fraction of this fertilizer N was present in the biomass N. Based on the fertilizer N present in the Fn (Table 4.8) and using a conservative Kn value of .68 (Shen et al., 1984), biomass N accounted for 22.4% of the immobilized fertilizer N in the NT barley treatment. In 1985, the biomass N only accounted for about 12.8% of the immobilized fertilizer N in the NT barley treatment.

The small amounts of immobilized fertilizer in the biomass was much less and not proportional to the large amounts of fertilizer N in the soil organic fraction. Fertilizer N immobilization accumulation in the non-biomass organic N fraction could have occurred through: biomass assimilation of fertilizer N and conversion to the more resistant organic N fraction, or direct reaction of fertilizer NH_4^+-N or NH_3 with soil constituents.

Considering the first explanation, spring incorporation of barley straw residue in CT plots would have resulted in substantial immobilization of soil mineral N very early in the growing season. In 1984, a dry spring, broadcast fertilizer would have remained on the soil surface. Later in the growing season precipitation would have washed fertilizer N deeper into the soil surface layer (0-75 mm). Thus, good moisture conditions and abundant crop residue available in the NT plots for winter wheat and barley, would have resulted in substantial fertilizer N immobilization (6.35 and 10.99 kg ha, respectively).

The calculated potential for fertilizer N immobilization based soley on the crop residue from the previous crop, indicates that the immobilized fertilizer N could have occurred by biomass assimilation. For example, winter wheat straw yield in 1983 for the NT treatment was approximately 4430 kg ha^{-1}. Assuming 45% C by weight, a C utilization efficiency of 50% (McGill et al., 1981), and a soluble C concentration of 14% (Reinertsen et al., 1984), the readily available C would be 140 kg ha^{-1}. Using a biomass C/N ratio of 6.7 (Shen et al., 1984) the total N immobilization would be 20.9 kg ha^{-1}. Soluble N in the straw was estimated at 10 kg ha^{-1} (Reinertsen et al., 1984). Biomass production would still require 10.9 kg ha^{-1} of inorganic N. In 1984 and 1985, fertilizer N immobilization in the barley treatments ranged from 3.93 to 12.67 kg ha^{-1}.

By midseason, as soil conditions became much drier and less substrate available, mineralization conditions dominated and biomass fertilizer N was either converted to resistant organic N or mineral N. At midseason the amount and %NDFF of mineral N was greater in the CT than the NT plots (Fig. 4.2 and Fig. 4.3). The fertilizer N in the Fn had decreased to low amounts in both tillage systems (Table 4.8).

Rapid loss of fertilizer N from biomass can occur under some field conditions. Carter and Rennie (1984b) found a decrease from 31.2%

of fertilizer N (100 kg ha^{-1}) in the biomass to only 4.8% later in the growing season at a Lethbridge site. Widely fluctuating moisture and temperature at the soil surface was suggested as a reason for the short half-life for the microbial biomass N.

The %NDFF in the Fn was similar for tillage treatments for barley (2.92%), but for winter wheat, %NDFF ws 1.44% for NT plots and .93% for CT plots. The tillage effect for winter wheat plots could be caused by very small amounts of available C in the CT plots compared to NT plots since CT summerfallow promotes fast crop residue decomposition.

In 1985, precipitation at seeding resulted in fertilizer N immobilization of 9.71 kg ha^{-1} in CT and 11.04 kg ha^{-1} in NT since substantial substrate was available for biomass in both tillage systems. For winter wheat a fertilizer N immobilization of 6.86 kg ha^{-1} for CT and 3.42 kg ha^{-1} for NT was quite large, considerating the small level of crop residue remaining after CT summerfallow. Some of the N immobilization could have been associated with biomass in the rhizosphere of the rapidly growing winter wheat crops. The greater soil biomass C of 664 kg ha^{-1} for CT compared to only 484 kg ha^{-1} for NT plots at seeding time reflected more favorable conditions for biomass in CT than NT. As in 1984, with subsequent dry conditions, the biomass decreased and biomass fertilizer N was mineralized or converted to resistant material. At midseason the size and %NDFF of the inorganic N fraction showed only a slight inverse relationship with fertilizer N immobilization in each tillage system (Fig. 4.2 and Fig. 4.3). The %NDFF in the Fn for winter wheat was .79% for CT and 1.87% for NT but there was no effect of tillage on barley plots.

Considering the second explanation, part of the immobilized fertilizer N in the non-biomass organic N may have occurred NH_4^+ fixation by clay minerals or NH_3 fixation by organic matter. Ammonium fixation was probably not a significant process as clay fractions of southern Alberta soils are comprised mainly (54%) of smectite (Dudas and Pawluk, 1981) and surface soil layers containing montmorillonite clay have a low capacity for NH_4^+ fixation (Stevenson, 1986). Ammonia fixation is favored by organic matter, alkaline fertilizers (eg. urea), and a high soil pH (Stevenson, 1986). In the current study, a close to neutral pH (7.1) and a NH_4NO_3 fertilizer source suggested that NH_3 fixation by organic matter was not the major fertilizer N fixation process.

The original hypothesis was supported since the amount of fertilizer N immobilization was related to the amount of crop residue and surface soil moisture. The most plausible fertilizer N fixation pathway appeared to be biomass assimilation, but NH_3 fixation cannot be ruled out entirely until research work is carried out to quantify this process under the conditions of this study.

Mineral N production was much greater for the CT than the NT treatment for the continuous spring wheat fertilizer residual N plots. The reason for this deviation from other crops in 1985 could relate to a greater surface buildup of resistant organic material. This soil mulch layer would favor greater biomass growth and increased immobilization of fertilizer N in the NT than the CT treatment. This efficient N cycling in the NT treatment sustains a greater amount of soil organic matter as more organic matter promotes better crop growth which subsequently produces more organic matter. This self-perpetuating cycle does not seem as evident in the 3-year rotation which includes fallow. This study suggests that fallow tends to remove differences in crop residue between tillage treatments so that a buildup of organic matter in the NT compared to the CT treatment does not occur.

Fertilizer N immobilization differences between tillage treatments and its effect on soil mineral N were large enough to affect crop N concentration even though soil mineral N remained relatively high. Fertilizer N immobilization at a critical early time of the growing season combined with some fertilizer N being stranded on the dry soil surface could explain the previous contradiction. Greater fertilizer N immobilization for the NT than the CT barley treatment in 1984 (Chapter 2, Table 2.7) caused less grain and straw protein at the 25 kg ha^{-1} fertilizer N rate for NT than the CT treatment but not at the higher N rate. In 1983, fertilizer N immobilization was not measured but, again, decreased grain and straw N contents were found in NT than CT at the lower N rates for barley straw (Chapter 2, Table 2.7) and for winter wheat grain and straw (Chapter 2, Table 2.6).

Fertilizer N immobilization was controlled by the effect of the amount and timing of growing season precipitation and tillage system architecture. Banding fertilizer N below the surface soil residue layer could reduce fertilizer N immobilization but would leave the fertilizer N more susceptible to leaching.

4.5 CONCLUSIONS

Greater early season biomass growth in NT treatments compared to CT treatments and accompanying increases in biomass N suggested that CT biomass was less competitive with the growing crop for soil N than NT biomass. In CT treatments, biomass demand for N occurred before the period of maximum uptake of N by the crop and subsequent mineralized N could be utilized by the crop. In contrast, the biomass increase in NT compared to CT treatments later in the growing season was more competitive with the growing crop for N and would not release N in time for crop utilization. Competition for N at a crucial time could produce lower crop yields and/or lower grain N contents for the NT than the CT system.

Greater biomass growth in CT than NT treatments for spring seeded crops was apparently caused by higher soil temperatures. Increased biomass growth in CT than NT treatments for winter wheat in the spring was dependent upon greater soil moisture and crop residue incorporation. Greater surface soil moisture (0-75 mm) promoted better biomass growth in NT than CT treatments for crops later in the growing season. Identification of the soil parameters that govern biomass growth will permit development of tillage practices that minimize biomass N immobilization when biomass is competing with crops for N but maximize biomass N uptake after this period to conserve soil N.

The incorporation of fertilizer N into the soil organic phase was attributed to biomass assimilation and reaction of NH_3 with the soil organic matter. Fertilizer N incorporation into the active fraction of biomass appeared to be the main process and was related to the relative amount of high C/N crop residue material present in the soil when fertilizer N was moved into the soil surface (0-75 mm) by precipitation. The effect of amount of crop residue and weather on fertilizer N immobilization complicated prediction of crop N requirements. The persistence of greater net immobilization conditions in NT than CT treatments through the growing season generally reduced fertilizer N efficiency but favored soil N conservation. The reaction of NH_3 with soil organic matter may have also accounted for part of the fertilizer N immobilization.

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5. CONCLUSIONS

5.1 GENERAL DISCUSSION

This study investigated the impact of conventional tillage and no-tillage on crop production and long-term soil quality for two crop rotations, a 3-year rotation - winter wheat-barley-fallow, and continuous wheat. Field experiments were carried out at Lethbridge and Vauxhall on a loam and clay loam soil, respectively, in the semi-arid region of southern Alberta (long-term growing season rainfall - 94.1 mm at Lethbridge and 95.6 mm at Vauxhall). Three fertilizer treatments of broadcast ^{15}N labelled NH_4NO_3 were superimposed on the main tillage plots of the two grain rotations in a split-split-plot design.

The soil parameters measured were temperature, moisture, bulk density, mineral N, total N, and organic C. The soil biomass parameters measured were biomass C, flush of N, and potential microbial activity. Potential microbial activity provided an estimate of available crop residue substrate. Crop parameters were grain and straw yield, grain and straw N concentration. The %NDFF was measured in each soil, biomass, and plant fraction, and the amount of fertilizer N in each fraction was calculated. Crop residue prior to seeding (Appendix 6.9) was estimated from grain and straw yields and previous measurements of crop residue decomposition.

The effects of tillage induced changes in soil parameters on crop yield, crop N concentration, biomass C and N, and fertilizer N immobilization were assessed. From this information, it is now possible to look at the total picture and determine the important interrelationships between crop growth, biomass growth, and the soil N cycle. Crop growth and biomass are linked through crop residue input and the mineral N pool as controlled by the soil N cycle.

Biomass growth responded differently from crop growth to tillage-induced changes in soil parameters. Biomass was greater for CT than NT treatments in the spring (Chapter 4, Tables 4.1, 4.2, and 4.3) as a result of higher soil temperatures in CT than NT treatments for spring seeded crops. Soil temperature had no effect on crop growth (Chapter 3, Table 3.11). Greater surface soil moisture (0-75 mm) (Chapter 3, Figs. 3.1 and 3.2) in the spring favored early crop growth and better harvest yields in NT than CT treatments. Biomass was greater for NT than CT treatments (Tables 4.1 and 4.2) as the season progressed since greater surface crop residue (Tables 4.9 and 4.10) resulted in greater soil moisture in NT than CT treatments. Tillage induced changes in soil parameters as a result of crop residue incorporation affected fertilizer N immobilization and the soil N cycle, with the magnitude of the effect dictated by the weather and system architecture. In years with little precipitation, crop residue incorporation in CT treatments increased crop residue decomposition relative to NT treatments (Tables 4.9 and 4.10) and as the season progressed, net mineralization conditions predominated in CT treatments while NT treatments tended toward net immobilization (Table 2.10) due to the persistence of high C/N crop residue on the soil surface in both spring seeded crops and winter wheat.

Fertilizer N immobilization was affected by crop, tillage, and precipitation timing. Fertilizer N immobilization was favored by greater amounts of crop residue coinciding with precipitation events which produce good surface (0-75 mm) soil moisture conditions. When early growing season soil conditions were dry and precipitation occurred later in the growing season (i.e. 1983 and 1984), a greater amount of high C/N crop residue occurred in the NT than in the CT plots, and fertilizer N immobilization was much greater for NT than CT (Table 2.10). Consequently, decreased crop N concentrations occurred in NT treatments compared to CT treatments at the lower fertilizer N rate (Table 2.7), but there was no difference in crop N concentration between tillage treatments at the highest fertilizer N rate. Small amounts of fertilizer N in the Fn (Table 4.8) during the growing season even when substantial amounts of fertilizer N were immobilized suggested that only a small fraction of the total biomass was active. This active fraction of the biomass turned over rapidly, probably accelerated by wetting and drying conditions, and incorporated fertilizer N was rapidly converted to more resistant organic material. Reaction of NH_3 with organic matter could also have contributed to fertilizer N immobilization in the organic N fraction.

In 1985, some precipitation occurred at the time of seeding but the rest of the growing season was very dry. For spring seeded barley, fertilizer N immobilization was substantial (average = 10.4 kg ha^{-1}) in both tillage treatments (Table 4.8) and caused a straw N concentration response (Table 2.7) to fertilizer N. In the continuous wheat rotation, as in previous years, higher organic C in the NT treatment resulted in much lower soil mineral N in the NT than the CT treatment by mid-season in the 0-75 mm soil layer (5.57 vs. 16.45 kg ha^{-1}, respectively) (Fig. 4.4). Fertilizer N immobilization was 6.86 kg ha^{-1} in the CT compared to 3.42 kg ha^{-1} in the NT treatment for winter wheat as a result of less moisture in the NT than the CT treatment. Greater fertilizer N immobilization in the NT treatment was accompanied by slightly higher soil mineral N values by mid-season in the 0-75 mm soil layer (9.81 vs. 6.81 kg ha^{-1} for NT and CT, respectively) (Fig. 4.4).

The %NDFF values (Figs. 2.2 and 2.3) were greater for NT than CT treatments for spring seeded crops. Greater soil moisture (0-75 mm) in NT than CT treatments probably led to greater root proliferation in this zone where fertilizer N was concentrated. In CT treatments, roots may have grown deeper in soil where there was less fertilizer N.

The %NDFF values (Figs. 2.2 and 2.3) for winter wheat followed a different pattern. The %NDFF values were greater for NT treatments when the growing season was wet but the values were greater for CT treatments when the growing season was drier. Soil conditions that favored fertilizer N immobilization also favored fertilizer N uptake.

The effect of tillage induced soil parameter changes on short-term primary production and organic matter decomposition over time determines the equilibrium level of organic matter in the soil which affects long-term soil quality and ultimately controls long-term crop productivity. Previous studies under more humid climates (Rice et al., 1986; Lamb et al., 1985) reported the lower availability of soil N in NT compared to CT was only a transient effect and eventually N availability was similar for tillage systems. This study, conducted in a semi-arid area, revealed different results.

In the continuous wheat rotation in years with low growing season precipitation, crop yields (Chapter 2) were generally greater with NT than CT. Conversely, crop residue decomposition and mineral N production were greater in CT than NT treatments. Under dry conditions, crop residue decomposition was delayed by drying of the soil surface. This difference between production and decomposition in tillage treatments resulted in greater organic matter content in NT soil than CT soil. As the organic matter accumulated, the associated organic C helped promote greater net immobilization conditions in the NT than the CT soil. Less crop N uptake and greater mineral N production under CT than NT can lead to greater mineral N losses through leaching and a less efficient soil N cycling. Organic matter accumulation in the NT treatment produced a positive feedback on itself, as increased organic matter favors greater crop yields which, in turn, produced more organic matter.

In the 3-year rotation, although crop yield and net N immobilization was generally greater (Chapter 2) in NT than CT, an increase in organic matter was not evident. It is possible that with fallow in the rotation, the buildup of organic C was prevented since organic matter decomposition would proceed through the fallow season under favorable temperature and moisture conditions with minimal residue input.

The results from this study support the original hypotheses by demonstrating that:

(1) Improved soil moisture in NT than CT treatments produced greater crop yields when growing season precipitation was limited.

(2) Tillage-induced changes in soil moisture, soil temperature, and crop residue affected the soil N cycle and indirectly, crop N concentration.

(3) In the continuous wheat rotation there was more efficient soil N cycling and improved long-term soil quality in the NT than the CT system.

5.2 GENERAL CONCLUSION

a) Based on crop yields, NT was superior to CT for this semi-arid region. Greater yields for NT than CT grain crops were associated with greater surface soil moisture levels in NT than CT treatments, particularly when dry soil conditions were prevalent in the early part of the growing season. Conserving soil moisture at seeding should be a main objective for growers. Seedbed preparation tillage should be avoided if possible and fertilizer placements used that minimize soil disturbance.

b) Crop yield and crop N concentration increases with greater increments of fertilizer N were more often observed in NT than in CT treatments for spring seeded crops, when conditions promoted N immobilization. Fertilizer N immobilization was favored by ample soil moisture and crop residue in proximity with the broadcast fertilizer N. Generally, greater fertilizer N immobilization for NT than for CT treatments suggested that fertilizer N should be placed below the crop residue layer to minimize fertilizer N immobilization.

c) Greater amounts of soil water were conserved by NT compared to CT plots on a Lethbridge loam soil but not on a Chin clay loam. Variation in soil moisture conservation between NT and CT for different soil types was attributed to textural layering and mulch layer thickness. Knowledge of the effect of soil texture, soil organic matter, and textural layers on soil moisture conservation are necessary to predict which tillage system will be more favorable for a given soil type.

d) In years with low growing season precipitation, greater crop yields and reduced crop residue decomposition and mineral N production occurred for NT compared to CT treatments. This imbalance between primary production and organic matter decomposition, differing between tillage treatments, resulted in greater organic matter content in NT than CT soil in the continuous wheat rotation. Organic matter accumulation was not yet evident in NT treatments in the three-year rotation, probably because of the masking effect of the fallow treatment. Based on long-term soil quality, NT compared to CT was a superior tillage system for this semi-arid region, particularly for continuous cropping rotations.

e) Greater biomass growth in CT than NT treatments for spring seeded crops was apparently caused by higher soil temperatures. Increased biomass growth in CT than NT treatments for winter wheat in the spring was attributed to greater soil moisture and crop residue incorporation. Later in the growing season, greater crop residue levels caused greater improvement in soil moisture in NT than CT treatments which encouraged better biomass growth. In CT treatments, biomass demand for N occurred before the maximum uptake of N by the crop and subsequent mineralized N could be used by the crop. In contrast, the greater biomass increase in NT later in the growing season was more competitive with the growing crop for N and would not release N in time for crop utilization. In certain years, biomass competition for N at a crucial time could produce smaller crop yields and/or decreased grain N contents for the NT than the CT system.

f) The incorporation of fertilizer N into the soil organic phase was attributed mainly to biomass assimilation and subsequent transformation into more resistant organic matter. Fertilizer N immobilization was favored by ample soil moisture and high C/N crop residue material in proximity to the fertilizer N. Fertilizer N immobilization was greater in NT than CT treatments for spring seeded crops in years when growing season precipitation was below average and occurred later in the season. The interactive effect of crop residue and weather on fertilizer N immobilization makes the forecasting of crop N requirements difficult. Identifying the soil factors that influence fertilizer N immobilization will assist researchers in making fertilizer placement and tillage recommendations that will maximize fertilizer N efficiency and soil N conservation.

5.3 REFERENCES

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6. APPENDIX

6.1 MICRO-PLOTS: FERTILIZATION, PLANTS, AND SOIL SAMPLING

The main purpose of this study was to test the effect of several soil variables on crop fertilizer N uptake and on N cycling in the soil. This type of study required repetitive soil sampling over two years. Plots of 1 m^2 were used for broadcast ^{15}N NH_4NO_3 without any unnatural boundary around the perimeter. This type of plot is probably not the best choice for achieving high recovery of fertilizer N but has the advantage of not disturbing the soil and does not interfere with soil temperature and soil moisture gradients. Private communication with Dr. Keith W. Steele (1983) revealed that microplots with walled boundaries affected results in field experiments in New Zealand compared to microplots without boundaries.

Fertilizer N was sprayed with a broadcast application. This uniform application allowed several subsequent probe samplings to obtain a representative soil sample without removing much soil. A major disadvantage was that obtaining an accurate depth sample from the top few cm of soil was difficult with soil probes.

At harvest, the complete 1 m^2 was harvested. Plans to harvest 0.49 m^2 in the plot center was not carried out in 1983 and 1984 due to uneven growth as a result of poor germination and drought. In 1985, 0.49 m^2 in the plot center was harvested separately from the rest of the 1 m^2 sample and analyzed for $^{15}N/^{14}N$ content. This inner square would not be affected as much by losses of fertilizer N to plants outside the

1 m^2 sampling area. The total dry matter yield was represented by the sum of yields from the complete 1 m^2 area. In the spring and fall soil samples were taken within an 0.7 m x 0.7 m area centered on the 1 m^2 area, from the following depth~~s~~: 0-75 mm, 75-150 mm, 150-300 mm, 300-600 mm, 600-900 mm, and 900-1200 mm. In the fall, soil samples were taken from within the microplot area with the same increments. At mid-season, depths were: 0-75 mm, 75-150 mm, and 150-300 mm. In the spring, and at mid-season, soil samples consisting of four cores, 20 mm in diameter, were taken from each microplot. In the fall there were six cores, 40 mm in diameter.

Soil samples were mixed in the field and transported in insulated coolers to 5°C storage rooms. Soil samples were extracted with 2N KCl within two days. The remaining soil sample was air-dried and kept for total N analysis.

Top growth and main roots were harvested from each microplot in the fall. Grain samples were threshed, dried at 65°C, and ground through a 1-mm sieve. Chaff, straw, and roots were dried at 65°C and ground together through a 1-mm sieve. The main roots were pulled out with the grain straw from the 0-150 mm soil layer. The roots were dried and the soil brushed off. Plant roots were ground through a 1-mm sieve.

6.2 STATISTICAL ANALYSES

Analysis of variance was generally carried out on a split-plot design: reps tillage/fertility: reps = 5, tillage = main plots = 2; fertility = subplots = 3. For comparison of some soil parameters between rotations, a split-split-plot design was used: reps crops/tillage/fertility: reps = 5, crops = 3, tillage = 2, fertility = 3. Standard errors for testing effects of the factors applied to the main plots and subplots and their interactions were as described by Little and Hills (1978). Comparison of soil parameters were carried out separately for each depth. Pearson correlation coefficients between grain yield and various soil parameters were calculated using the SAS procedure CORR (SAS Institute Inc., 1985).

6.3 SOIL BULK DENSITY (Mg m^{-3}) AT LETHBRIDGE AND VAUXHALL FOR THE 3-YR ROTATION AND CONTINUOUS WHEAT AFTER FALL HARVEST IN 1984

Rotation	Soil depth (mm)	Lethbridge CT	Lethbridge NT	Vauxhall CT	Vauxhall NT
3-yr rotation	0- 75	1.26	1.28	1.27	1.26
	75- 150	1.29	1.28	1.31	1.28
	150- 300	1.27	1.31	1.36	1.41
	300- 600	1.22	1.31	1.42	1.43
	600- 900	1.51	1.51	1.54	1.52
	900-1200	1.50	1.46	1.60	1.59
Continuous wheat	0- 75	1.24	1.28	1.25	1.22
	75- 150	1.27	1.27	1.29	1.31
	150- 300	1.28	1.29	1.36	1.37
	300- 600	1.30	1.23	1.45	1.41
	600- 900	1.32	1.42	1.57	1.59
	900-1200	1.41	1.36	1.61	1.60

6.4-a SOIL TEMPERATURES (^{o}C)* FOR CT AND NT IN 1983 AT THE LETHBRIDGE SITE

Weeks after planting	Winter wheat		Barley		Spring wheat	
	CT	NT	CT	NT	CT	NT
2	21	23	22	21	22	21
3	24	28	26	25	26	25
4	22	24	24	22	24	23
5	24	24	23	23	23	24
6	29	30	30	30	31	31
7	27	28	28	29	28	28
8	24	25	25	25	25	25
9	27	27	28	29	29	29
10	32	32	34	34	39	36

*^{o}C at the 2-cm soil depth at 1530 hr.

6.4-b SOIL TEMPERATURES (^{o}C) FOR CT AND NT (0-900-mm LAYER) ON 83-06-24 AT THE LETHBRIDGE SITE

Soil depth (mm)	Winter wheat		Barley		Spring wheat	
	CT	NT	CT	NT	CT	NT
20	23.5	24.0	23.0	23.5	23.5	23.0
100	20.5	20.5	20.5	20.5	20.0	21.0
350	18.0	17.0	18.0	18.0	16.0	18.0
400	16.5	15.0	17.0	18.0	16.0	18.0
600	15.0	14.0	15.0	16.5	15.0	16.5
900	13.0	12.0	13.5	14.0	13.5	14.0

6.5 SOIL MOISTURE CONTENTS AT VARIOUS SOIL WATER POTENTIALS AND PARTICLE SIZE ANALYSES FOR THE 0-600 mm SOIL LAYER AT LETHBRIDGE AND VAUXHALL

	Soil depth (mm)	Tension (MPa) 0.02	0.5	1.5	Particle size Sand	Silt	Clay	Texture class
		moisture g kg^{-1}			%			
Lethbridge	0-150	206	111	109	49.5	31.5	19.0	L
	150-300	232	144	141	40.2	31.0	28.7	CL
	300-600	248	146	143	44.5	25.5	30.0	CL
Vauxhall	0-150	253	155	154	39.8	29.7	30.5	CL
	150-300	249	159	155	37.6	28.7	33.7	CL
	300-600	249	159	157	33.0	31.6	35.5	CL

6.6 NATURAL ABUNDANCE OF ^{15}N (%) IN THE LETHBRIDGE LOAM SOIL

Soil depth (mm)	Total N CT	Total N NT	Inorganic N CT	Inorganic N NT
0- 75	.37014	.36927	.36746	.36689
75- 150	.36947	.36921	.36725	.36642
150- 300	.36999	.36922	.36640	.36626
300- 600	.37037	.36888	.36643	.36632
600- 900	.36954	.36923	.36967	.36638
900-1200	.36951	.36948	.36859	.36638

NH_4NO_3 Fertilizer .36653.

Labelled $^{*}NH_4{}^{*}NO_3$ 1984 - 4.9895.

Labelled $^{*}NH_4{}^{*}NO_3$ 1985 - 5.4765.

6.7-a %NDFF FOR GRAIN AND STRAW FOR VAUXHALL (1984) AND LETHBRIDGE (1985)

		Grain Fertilizer		Straw Fertilizer	
Crop*	Till	Low	High	Low	High
		Vauxhall, 1984			
WW	CT	2.0	5.1	2.0	3.7
	NT	3.3	5.7	2.5	4.4
B	CT	11.3	20.2	11.5	21.7
	NT	10.0	21.2	10.1	23.8
SW	CT	9.1	15.8	9.9	16.8
	NT	10.5	20.2	11.9	21.7
		Lethbridge, 1985			
WW	CT	7.30	9.97	7.82	10.82
	NT	6.75	8.53	7.33	9.64
B	CT	8.09	11.14	8.76	11.91
	NT	10.45	15.00	11.33	16.78
B†	CT	6.27	7.47	6.29	9.04
	NT	6.17	8.15	6.10	8.35
SW†	CT	8.60	13.21	8.21	11.52
	NT	7.80	12.12	7.38	10.77

*WW = winter-wheat - 15 kg N ha^{-1}, 30 kg N ha^{-1}.
B = barley - 25 kg N ha^{-1}, 50 kg N ha^{-1}.
SW = spring wheat - 75 kg N ha^{-1}, 50 kg N ha^{-1}.

†Residual N plots; fertilized in 1984.

6.7-b %NDFF FOR GRAIN AND STRAW FOR LETHBRIDGE (1984) AND VAUXHALL (1983)

		Grain Fertilizer		Straw Fertilizer	
Crop*	Till	Low	High	Low	High
		Vauxhall, 1983			
WW	CT	5.4	9.7	5.9	10.6
	NT	6.4	11.7	5.5	10.5
B	CT	12.9	19.6	12.0	18.8
	NT	16.5	30.2	16.3	29.2
SW	CT	10.9	19.7	10.2	17.7
	NT	13.8	28.4	13.7	27.1
		Lethbridge, 1984			
WW	CT	8.1	14.5	6.6	11.8
	NT	8.9	15.7	7.6	13.0
B	CT	15.4	27.5	15.2	28.1
	NT	17.7	31.6	19.1	32.2
SW	CT	12.4	20.6	12.4	20.7
	NT	16.5	30.1	17.1	31.1

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*WW = winter wheat - 15 kg N ha^{-1}, 30 kg N ha^{-1}.
B = barley - 25 kg N ha^{-1}, 50 kg N ha^{-1}.
SW = spring wheat - 25 kg N ha^{-1}, 50 kg N ha^{-1}.

6.8-a **LABELLED FERTILIZER N RECOVERY (kg ha^{-1}) IN THE TOTAL N SOIL FRACTION FOR FERTILIZER RESIDUE CROPS FROM FOUR SOIL LAYERS AT LETHBRIDGE IN 1985**

Soil depth (mm)	Barley		Fallow		Spring wheat	
	CT	NT	CT	NT	CT	NT
85-04-18						
0- 75	6.49	6.93	9.56	9.98	10.84	10.42
75-150	.76	.83	2.24	2.21	1.86	2.18
150-300	4.18	2.06	4.61	3.86	6.51	5.68
300-600	2.81	3.94	2.23	3.14	2.45	3.41
Total	14.24	13.76	18.64	19.19	21.66	21.69
85-06-13						
0- 75	2.59	4.12	8.34	8.60	4.89	4.26
75-150	1.54	1.25	1.49	1.89	.99	1.67
150-300	2.06	1.31	2.88	2.82	3.70	2.77
300-600	3.51	3.49	4.68	4.79	5.40	6.24
Total	9.70	10.17	17.39	18.10	14.98	14.94
85-08-21						
0- 75	3.25	6.16	4.56	7.01	3.33	3.97
75-150	1.48	1.33	6.71	4.08	1.73	1.41
150-300	1.26	.94	2.52	2.83	3.03	3.01
300-600	3.59	3.55	4.26	4.23	5.53	8.19
Total	8.99	11.98	18.06	18.15	13.62	16.58

6.8-b **LABELLED FERTILIZER N RECOVERY (kg ha^{-1}) IN THE TOTAL N SOIL FRACTION FOR FOUR SOIL LAYERS AT LETHBRIDGE IN 1985**

Soil depth (mm)	Winter wheat		Barley	
	CT	NT	CT	NT
85-06-03				
0- 75	13.57	14.24	22.25	21.01
75-150	2.65	2.18	1.83	2.23
150-300	2.73	2.90	2.77	2.35
300-600	3.10	3.04	4.86	4.23
Total	22.05	22.36	31.71	29.82
85-08-21				
0- 75	7.76	8.01	11.99	12.50
75-150	6.99	8.37	12.12	8.02
150-300	1.75	1.53	1.89	1.74
300-600	3.29	3.94	5.79	5.81
Total	19.79	21.85	31.79	28.06

6.8-c LABELLED FERTILIZER N RECOVERY (kg ha^{-1}) IN THE TOTAL N SOIL FRACTION AT LETHBRIDGE IN 1983 AND 1984

Soil depth (mm)	Winter wheat		Barley		Spring wheat	
	CT	NT	CT	NT	CT	NT
83-08-18						
0- 75	2.40	2.93	7.82	8.01	7.89	7.00
75-150	1.18	.88	1.31	1.04	2.18	2.10
150-300	1.26	1.16	1.21	1.54	1.31	1.28
300-600	1.84	1.56	2.05	1.82	1.92	2.52
Total	6.68	6.53	12.39	12.41	13.30	12.90
84-07-15						
0- 75	5.74	7.01	8.34	13.52		
75-150	3.40	1.46	8.87	1.99		
150-300	1.68	1.38	3.36	3.23		
Total	11.81	10.85	20.57	18.74		
84-08-20						
0- 75	5.59	6.62	8.96	10.47	11.49	11.60
75-150	3.49	1.83	4.98	2.95	6.35	5.03
150-300	1.19	1.40	3.13	1.98	3.02	2.78
300-600	.83	1.28	2.82	2.00	1.46	1.44
Total	11.10	11.13	19.89	17.40	22.32	20.85

6.9 ESTIMATED AMOUNTS OF CROP RESIDUE (kg ha^{-1}) PRIOR TO SEEDING CEREAL CROPS UNDER CT AND NT FROM 1983 TO 1985 AT LETHBRIDGE AND VAUXHALL

		3-year winter wheat		Barley		Continuous wheat	
Site	Year	CT	NT	CT	NT	CT	NT
Lethbridge	1983	1556	3247	6460	6663	1585	1737
	1984	1980	2769	3478	4282	1184	855
	1985	820	1887	2892	3932	186	550
Vauxhall	1983	619	1297	1730	2537	911	1227
	1984	1186	2905	1982	2410	1067	1370
	1985	1002	1105	1326	1452	99	305

Crop residue after harvest (straw, chaff, and main roots) x crop residue.

Crop residue remaining for each crop (Lindwall, 1986):

Crop	Period	CT	NT
Barley	2 winters + 1 summerfallow	35%	65%
Winter wheat	1 winter	85%	85%
Spring wheat	1 winter	83%	83%

6.10 REFERENCES

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